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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEAR

REPORT ON A SURVEY OF THE INFESTATION OF GRAIN BY INSECTS

BY

PROFESSOR J. W. MUNRO, D.Sc.

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LONDON
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PREFACE

THE willing co-operation of many of the industrial interests concerned led to the formation, in 1937, on the initiative of Mr. W. McA. Gracie, of the London and North Eastern Railway Company, of an informal committee to consider the problems arising from the infestation of grain by insects and similar pests. Approach to Government resulted in a meeting between the informal committee and the Department of Scientific and Industrial Research in March, 1938, when an outline of the programme of work and the organization required for a co-operative industrial research on the problem were considered.

To take advantage of the period of seasonal activity of the insects then approaching, the Department agreed to undertake responsibility for the first step in tackling the problem—i.e., a survey to discover as much as possible about the facts of infestation of cereals and cereal products in this country, from the time of harvest, or arrival at the port, up to delivery to the customer. The Department agreed to take this step if the industrial organizations would show proof of their interest by contributing towards the cost. This proof was rapidly forthcoming, and the survey was started in May, 1938.

At the request of the Department, the survey was undertaken by the Department of Zoology and Applied Entomology of the Imperial College of Science and Technology, under the direction of Professor J. W. Munro.

In order to maintain close contact with the industrial organizations, a Standing Conference was set up, under the chairmanship of Mr. W. McA. Gracie, to act as a consultative body. To this Conference all the co-operating organizations are entitled to appoint representatives. A Technical Consultative Panel, representative of special experience in many aspects of the problem, was also established to make this knowledge available for the benefit of the investigation. Further to assist Professor Munro and his colleagues engaged on the survey, a Grain Infestation Survey Committee was set up under the chairmanship of Sir Edwin Butler. Five research assistants were appointed for the work; Messrs. G. V. B. Herford, J. A. Freeman, A. E. H. Higgins and E. K. Yapp were wholly engaged in fieldwork, while the fifth, Mr. R. Howe, undertook the care and classification of the insects and mites collected and the rearing of stocks of them for experimental work. Mrs. A. M. Hughes was appointed as a part-time assistant for the systematic study of the mites, a group of animals whose classification required special knowledge.

The fieldwork of the survey was begun in May, 1938, and concluded in June, 1939.

This report was presented to the Standing Conference at a meeting held on 18th March, 1940. After consideration of the scientific evidence contained therein, the members of the Conference present unanimously agreed the following resolution:—

It being highly desirable in time of peace, and essential in time of war, that foodstuffs and other necessities of life should be saved from contamination, damage, and destruction;

It having been ascertained by scientific survey (conducted largely at the expense of industry and at the request of this Standing Conference) that pest infestation is widespread, ranging over many classes of commodities, and also over the structures and equipment whose use is essential to the storage, processing, trading, and transport of those commodities;

It also having been demonstrated that infestation by the large group of grain and fruit pests in particular is contagious and not spontaneous, and is neither inevitable nor incurable;

It having as a consequence been arranged by the Department of Scientific and Industrial Research at the request of this Standing Conference that a service providing for advice on prevention and cure, and for supervision of remedial treatment, shall be available to industry, which service is now in being;

It is therefore declared by this Standing Conference that good commercial practice requires that—

(*a*) Anyone receiving commodities into his ownership and care should satisfy himself, in his own interests, of their quality and condition.

(*b*) Nevertheless if,

(i) the person intending to deliver the commodity, or his agent, knows it to be infested, or if

(ii) a warehouseman, or provider of transport, knows that the accommodation or equipment into which it is proposed to receive the commodity is infested, or if

(iii) there is a development of infestation of a commodity whilst it is in the care of warehouseman or transport agent,

a suitable timely notification should be made, in confidence, to the owner, the receiver, or the provider of the services involved, as the case may be, by the person, warehouseman, or transport agent concerned.

(*c*) Only by such means can the opportunity be provided for preventing the spread of infestation.

(*d*) Any arrangement within a trade recognizing, as between buyer and seller, a permitted degree of infestation should not be taken as dispensing with the necessity for notification to any person, not party to the arrangement, whose accommodation or equipment may be utilized in the course of the trade in commodities whose infestation is known both to buyer and seller.

Department of Scientific and Industrial Research.
June, 1940.

STANDING CONFERENCE ON PEST INFESTATION OF PRODUCE

On 1st May, 1940, the Standing Conference on Pest Infestation of Produce included representatives appointed by the following organizations, undertakings, or persons:—

Association of British Chemical Manufacturers.
Association of Master Lightermen and Barge Owners.
Batchelor's Peas Ltd.
Brewers' Society.
British Sugar Corporation Ltd.
Cimex Ltd.
Clyde Navigation Trust.
Co-operative Wholesale Society.
Danish Bacon Co.
W. Edmonds & Co.
W. Edwards & Co.
Fumigation Services Ltd.
Great Western Railway Co.
Horlicks Ltd.
Imperial Chemical Industries Ltd.
Ind Coope & Allsopp Ltd.
S. Instone & Co. Ltd.
Institute of Brewing.
Leith Dock Commission.
London Association of Public Wharfingers Ltd.
London Cattle Food Trade Association.
London Chamber of Commerce.
London Fumigation Co. Ltd.
London, Midland & Scottish Railway Co.
London & North Eastern Railway Co.
Maltsters' Association.
Manchester Ship Canal Co.
Mersey Docks & Harbour Board Ltd.
G. Monro Ltd.
National Farmers' Union.
National Association of Corn & Agricultural Merchants.
National Federation of Corn Trade Associations:—
    London Corn Trade Association Ltd.
    Liverpool Corn Trade Association Ltd.
    Hull Corn Trade Association Ltd.
    Bristol Channel & West of England Corn Trade Association Inc.
    Glasgow Corn Trade Association.
    Incorporated Corn Trade Association of Leith.
    Irish Corn Trade Association Ltd.
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" For it will not only minister and suggest for the present many ingenious practices in all trades, by a connexion and transferring of the observations of one art to the use of another, when the experiences of several mysteries shall fall under the consideration of one man's mind; but further, it will give a more true and real illumination concerning causes and axioms than is hitherto attained."

BACON: *The Advancement of Learning*, Book II.

CONTENTS

PAGE

INTRODUCTION 1

THE CAUSES AND KINDS OF INFESTATION

Infestation by Insects 2

Infestation by Mites 8

PORTS

Transit Sheds 9

General Warehouses 11

Granaries 11

TRANSPORT 13

Appendix—Infestation of Cereals and Cereal Products found in ships' cargoes .. 18

SACKS 21

MILLS AND AGRICULTURAL MERCHANTS PREMISES

Flour Mills 23

Provender Mills 25

Oat Mills 28

Rice Mills 28

Agricultural Merchants' Premises 29

SEED MERCHANTS 31

FARMS 32

BREWERIES, MALTINGS, AND DISTILLERIES

Breweries and Maltings 35

Distilleries 37

SUMMARY AND CONCLUSIONS 38

LIST OF FIGURES

		PAGE
Grain Weevils—*actual size*		*Frontispiece*
FIG.		
1.	*Calandra Granaria*. Weevil grub in wheat	*facing* 6
2.	*Tribolium confusum*	,, 6
3.	*Ptinus*	,, 6
4.	Flour Beetles (*Tribolium*)	*Between pages 6 and 7*
5.	Grubs of Flour Beetle	
6.	Spider Beetles (*Ptinus*)	
7.	Grubs of Khapra Beetle (*Trogoderma*)	
8.	Khapra Beetle (*Trogoderma*)	
9.	White-Shouldered Moth (*Endrosis*)	
10.	White-Shouldered Moth (*Endrosis*)	*facing* 7
11.	Speckled or Seed Moth (*Borkhausenia*)	,, 7
12.	Distribution of grain and cereal products from overseas	,, 10

REPORT ON A SURVEY OF THE INFESTATION OF GRAIN BY INSECTS

INTRODUCTION

THE problem of the infestation of grain by insects was considered during the war of 1914-18 by a committee appointed by the Royal Society at the request of the Board (now Ministry) of Agriculture. This committee, known as the Royal Society Grain Pests (War) Committee, published ten reports on its work and distributed six memoranda relating to special aspects of it. The reports deal with laboratory studies of the biology of the grain-weevils, and in particular with the effect of air-tight storage and of low moisture content of the grain on their development, and with the biology, development and feeding habits of the four kinds of mite most commonly found in grain and flour. One of the reports gives a full list of insects associated with grain, including insects parasitic on grain-feeding beetles and moths.

It must be admitted that, except for Professor Newstead's work on mites, the work described in these reports was of rather long-range type. It was unco-ordinated and the war came to an end before any real attack on the practical problem could be made. In fact, the main reason for the present survey is that, although much semi-physiological information on grain insects is contained in the reports of the Royal Society's Committee, knowledge was still lacking concerning the different channels through which they are distributed and the extent to which these pests, most of them insects not indigenous to this country, had established themselves.

The main objects of the survey were therefore:

(1) to investigate the occurrence of grain-feeding insects throughout the country, especially of the weevils, *Calandra granaria* and *Calandra oryzae*.

(2) to ascertain whether these weevils attack home-grown grain in the field or in storage before threshing.

(3) to find out the extent to which insects infesting grain are brought into the country on imported grain and feeding-stuffs.

(4) to investigate the channels by which the insects are distributed throughout the country.

It will be realized that, with such a large area to cover within a single season, the results of the survey do not permit of precise comparison of the conditions of infestation prevailing in warehouses, farms, and mills at the same time of year. Thus, in order to determine whether the grain-weevils infest newly harvested, home-grown grain, the survey officers had to concentrate attention on the farms at the period immediately following harvest and were unable to give attention to the warehouses then. It is not, therefore, possible to make a comparison of the conditions prevailing in any one kind of grain store throughout the seasons of the year. Such a comparison must be made as time allows. Meanwhile the main objects of the survey have been attained.

The survey began with a rapid inspection of the warehouses, sidings, and rolling-stock of one of the railway companies; then attention was given to the warehouses and mills in the port by one group of officers, while another investigated the conditions prevailing in the brewing and distilling industries. Farms,

inland mills, and the premises of agricultural merchants next received attention, and the scope of the survey thus included all the grain or grain-using industries, from the large mills and granaries of Southampton and farms in the Isle of Wight to the distilleries and farms of the Isle of Skye.

The evidence obtained during the survey shows that grain-feeding insects are widespread throughout the country, and that every section of the industry is affected by this general infestation.

No evidence that the grain-weevils attack home-grown grain prior to or during harvesting, nor even after storage in the rick and threshing, has been obtained. Home-grown grain becomes infested only if it comes into contact or proximity with infested grain or feeding-stuff, usually of foreign origin, or when it is stored in barns, granaries, or warehouses, or is placed in bags or trucks which are infested.

While the survey shows that there is an endemic or " residential " population of grain-insects persisting indoors throughout the country, from the warehouses at the ports even to the remote inland farms, it also shows that there is a constant serious influx into our ports of grain-infesting insects brought with imported grain and feeding-stuffs.

The infestation of grain thus presents a dual problem, that of controlling the resident population of insects and that of controlling the imported population. If infestation is to be checked, action must be taken to deal with both populations.

It is evident that the most frequent infestation occurs on the premises of those who trade in, or house, the greatest variety of cereals and their products, both imported and home-grown, and of the commodities related to them. It would be surprising if this were not so.

That briefly is a summary of the findings of the survey. The evidence on which they are based is given in the sections of this report which follow and which, for convenience, deal with infestation in the various sections of the industry.

THE CAUSES AND KINDS OF INFESTATION

Infestation by Insects

The occurrence of weevils in wheat, barley, and rice is so frequent and so commonplace that it is almost taken for granted. The old belief that grain " generates " insects is almost dead, but a clear conception of the nature of infestation and of the conditions under which it arises is still lacking.

The first essential in the development of infestation is the accumulation of the vulnerable commodity in large quantities and its storage over a period of time sufficient to allow the grain-weevils or other insects to multiply. While, as the survey has shown, neither the grain-weevils nor any of the other major insect pests of grain occur and multiply out of doors in this country, in warmer, semi-tropical, and tropical countries these insects do live and breed out of doors. In parts of the United States of America, in Africa, and in India, the grain-weevils occur in the corn and rice fields, and infestation of grain may take place even before harvest. Once infestation has taken place, the rate at which it develops depends on the numbers of insects present and on the extent to which the conditions of storage are favourable to their multiplication.

Not all of the insects found in grain stores are equally destructive. The characteristics of the really injurious pests of grain are, briefly, early appearance on the grain (in warmer countries even before harvest), capacity to attack, enter, and lay eggs in whole grain, and ability to develop rapidly and breed quickly over a fairly wide range of temperature. Insects having these charac-

teristics are called " primary " pests. Insects of secondary or of lower importance are capable only of attacking or breeding in grain which is broken or which has already been broken into or damaged by other insects; or they require higher temperatures in order to survive and breed. An insect may be a primary pest in one country or climate and only of secondary or even of less importance in another. Thus, the beetle called *Rhizopertha dominica* is a primary pest of grain in India, but because it cannot thrive in our cooler climate is of little importance in Britain.

The primary pests in this country are the grain-weevils,[1] which directly attack whole grains; the flour-beetles,[2] which abound in offals and feeding-stuffs; the " khapra " beetles,[3] which are especially pests of maltings; the Mediterranean flour-moth or " mill-moth,"[4] which is so troublesome in mills; the " cacao-moth,"[5] which occurs on manufactured feeding-stuffs, notably nuts and cubes; and the spider-beetles,[6] which are general pests of warehouses. To this list must be added the mites, of which the flour-mites[7] are most widely prevalent.

Following or accompanying these primary pests are the secondary pests which are dependent on the conditions created by their forerunners. Where cereals or their products have been lying neglected over a long period, a large assemblage of insects of both categories may be found, and there is evidence that the kind of assemblage or association of insects found in grain and grain stores is not haphazard, but depends on a number of things, such as the kind of grain stored, on the amount of moisture it contains, on its country of origin and on the other goods stored in the warehouse. It is one of the functions of the entomologist to recognize these factors, to measure them, if possible, and to decide how and why they act, separately and collectively.

It is obvious that two of the most important factors which decide what insects will establish themselves in a store of grain—which decide the " nature of the infestation," as the entomologist calls it—are temperature and humidity. The need of fairly high temperatures for its development determines the ability of the beetle *Rhizopertha* to thrive in India and its inability to thrive in this country. The need for warmth explains why the " khapra " beetles are pests of maltings, and it has long been known that grain of low moisture content —below 8 per cent. of the grain by weight—is unsuitable as breeding-ground for the grain-weevils. The effects of temperature and humidity cannot be separated, and it is unfortunate that the study of the interplay of these two factors is one of the most difficult in practical entomology. But apart from that, the study of these factors as they affect grain insects becomes even more complex when it is remembered that the grain itself is responding or reacting to them. For example, grain itself heats because it is alive and breathing, but it may heat by fermenting and, moreover, infested grain heats by reason of the heat produced by the insects and mites themselves.

The study of this problem of the interplay of these factors, humidity and temperature, as they affect the infestation of grain is too little advanced to permit any exact assessment of how they can be controlled in grain stores to reduce infestation, but one point may be emphasized. The facile dictum that infestation of grain can be prevented by keeping its moisture content below a certain level (8 per cent.) takes no account of the conditions of storage of cereals and their products seen during the survey. It may be pointed out, too,

[1] *Calandra granaria* and *Calandra oryzae.*
[2] *Tribolium castaneum* and *Tribolium confusum.*
[3] *Trogoderma granarium* and *Trogoderma versicolor.*
[4] *Ephestia kühniella.*
[5] *Ephestia elutella.*
[6] *Ptinus tectus, Ptinus fur, Niptus hololeucus,* and *Trigonogenius globulum.*
[7] *Tyroglyphus farinae* and *Tyrophagus dimidiatus.*

that the infestation of grain by mites, or " mintiness " as it is called in some sections of the trade, is a consequence of changes taking place in grain stored under conditions favouring increase in its moisture content, conditions which are unavoidable in some of the warehouses seen during the survey.

The next factor affecting the nature of the infestation of a store of grain is whether the grains are clean and unbroken or dirty and broken. Clean, unbroken grains do not afford a breeding-ground for the secondary pests, and it is interesting to note that the nature of the infestation by secondary pests varies considerably in different sections of the industry because some pests thrive on grain that is simply broken, others thrive on grain that is crushed or milled, while still others seem to prefer grain that has been worked up into " branded " feeds, oilcakes, and nuts.

The variation in the nature of the infestation found in different sections of the industry is in the main due to the different kinds of cereals or their products handled by the different sections, with modifications in individual cases according to the prevailing temperature and humidity. Thus, those sections of the industry which handle the most varied kinds of grain and cereal products, coming from a number of different countries, including our own, show the most complex forms of infestation.

The following data for the infestation of grain in soils, in bulk, and in bags, and also for the infestation of " feeds," illustrate the preference of different insects for different kinds of grain or grain products, under different conditions of storage. The infestation by the common grain-weevil of grain in silos was 39 per cent., of grain in bulk 56 per cent., and of grain in bags 35 per cent., while in feeding-stuffs it was only 9 per cent. This weevil is a primary pest, breeding in whole grains. The flour-beetle, on the other hand, prefers broken, crushed or milled grain, and the infestation by it was: grain in silos 5 per cent., grain in bulk 6 per cent.,[1] grain in bags 37 per cent., and feeding-stuffs 52 per cent. The degree to which the different kinds of grain were infested by the flour-beetles is thus almost the reverse of that by the grain-weevils.

The most injurious pests of grain mentioned in this report belong to the groups familiarly known as insects and mites. The insects belong mainly to the orders commonly known as beetles and moths, but a few belonging to other orders are mentioned. It has unfortunately not been found possible wholly to avoid the use of " Latin " or " scientific " names for some of the insects. Only a few of the 150 insects found in grain or grain stores have common names, and even these common names are sometimes misleading. The moth (*Ephestia kühniella*) widely known to English-speaking entomologists as the " Mediterranean flour-moth " is known in the milling industry as the " mill-moth," while in the grain industry proper it has no particular name. In this country the moth (*Plodia interpunctella*) whose common name in the textbooks and scientific journals is the " Indian meal-moth " is far more a pest of dried fruits and of nuts than of cereals or their products. " Common " names are not, therefore, very helpful in ensuring that all will understand by them the same insects. Another reason why they are not satisfactory is that many more kinds of insects are known to the entomologist than are recognized by the public. The mill-moth or Mediterranean flour-moth belongs to a kind or " genus " of moths, the genus *Ephestia*, of which there are upward of 70 species, and of these only three or four have common names—the mill-moth (*E. kühniella*), the cacao-moth (*E. elutella*), and the fig-moth (*E. cautella*). Even these names are not precise, because to some entomologists the " fig-moth " means *Ephestia cautella*, while to others it may mean *Ephestia figuliella*. For these reasons the scientific names have been used in this report.

[1] These figures are percentages of *infested* grain. The amount of grain infested compared with clear grain is given on page 13.

The more important and more easily recognized pests of grain have already been mentioned under the grouping of weevils, flour-beetles, khapra-beetles, spider-beetles, and moths, and their names occur again and again in the sections which follow. Along with them, however, are other insects whose names, identity, and appearance are almost certainly unknown, or at least unfamiliar, to the general reader. These insects are included, and their names cited, because their presence means something to the biologist. The presence of parasitic insects tells the biologist that the infestation is of long standing because parasites rarely appear in numbers and in variety except in such circumstances. The finding of the little beetles belonging to the genus *Cryptophagus* suggests to the biologist that the conditions of infestation favoured the growth of moulds. The occurrence of the beetle *Rhizopertha dominica* almost certainly indicates that the infested produce is of Indian or Australian origin or has been in contact with, or in proximity to, grain of Indian or Australian origin, or, if the name appears in a list of insects recorded from a warehouse or sack depot, that these premises have held grain of Indian or Australian origin.

On the suggestion of the Standing Conference on Pest Infestation, the Department of Scientific and Industrial Research issued a leaflet on " Pests of Grain."[1] In that leaflet short descriptions of the more common and more injurious insects and mites are given, and the following is a short summary of them.

First place is given to the weevils, *Calandra granaria* and *Calandra oryzae* (Fig. 1 and frontispiece). These weevils are too well known to need further description, but the survey has confirmed the view that they are the most injurious of all the insects infesting grain in this country.

Rarely injurious to whole grain, but abundant in broken grain and in meals and feeding-stuffs, are the flour-beetles, *Tribolium castaneum* and *Tribolium confusum* (Figs. 2, 4, and 5).

Next in importance are the spider-beetles (Figs. 3 and 6). The most widely prevalent is the species *Ptinus tectus*, which, while usually regarded as a general warehouse pest and of secondary importance, is now reported as quite a serious pest of grain. Closely resembling it is the species *Ptinus fur*, which is, however, less widespread. A spider-beetle rounder and more brightly golden coloured than the *Ptinus* species is called *Niptus hololeucus*, while a fourth spider-beetle, already mentioned as associated with South American grain, is *Trigonogenius globulum*.

The khapra-beetles (Figs. 7 and 8), *Trogoderma granarium* and *Trogoderma versicolor*, are relatively newcomers to this country, and are of greatest importance in the brewing and distilling industry. Warmth is essential to their development and increase.

These are the more important beetles recorded in the survey, but accompanying them are several which, though less destructive, are of interest as showing how the kinds of infestation occurring vary with such factors as temperature and humidity, origin of the grain or feeding-stuffs affected, degree of cleanliness in the premises, and period of storage.

Of the moths recorded in this report four species occur frequently, the " mill-moth " or " Mediterranean flour-moth," *Ephestia kühniella*, the " seed-moth," *Borkhausenia pseudospretella* (Fig. 11), the " Indian meal-moth," *Plodia interpunctella*, and *Endrosis lacteella* (Figs. 9 and 10). It is noteworthy that all of these moths are sometimes found together infesting such goods as Plate middlings and offals, and it is evident that, broadly speaking, they are pests of cereal products or cereal debris rather than of the grain itself. Other moths

[1] "Common Pests of Grain and other Stored Produce," H.M. Stationery Office (1939), 3*d*. net. Supplementary wallchart, 4*d*. net.

Calandra granaria.

Weevil grub in wheat.

FIG. 1.

Tribolium confusum.

FIG. 2.

Ptinus.

FIG. 3.

[The small figures show the actual size of the insects.]

(*To face page* 6.

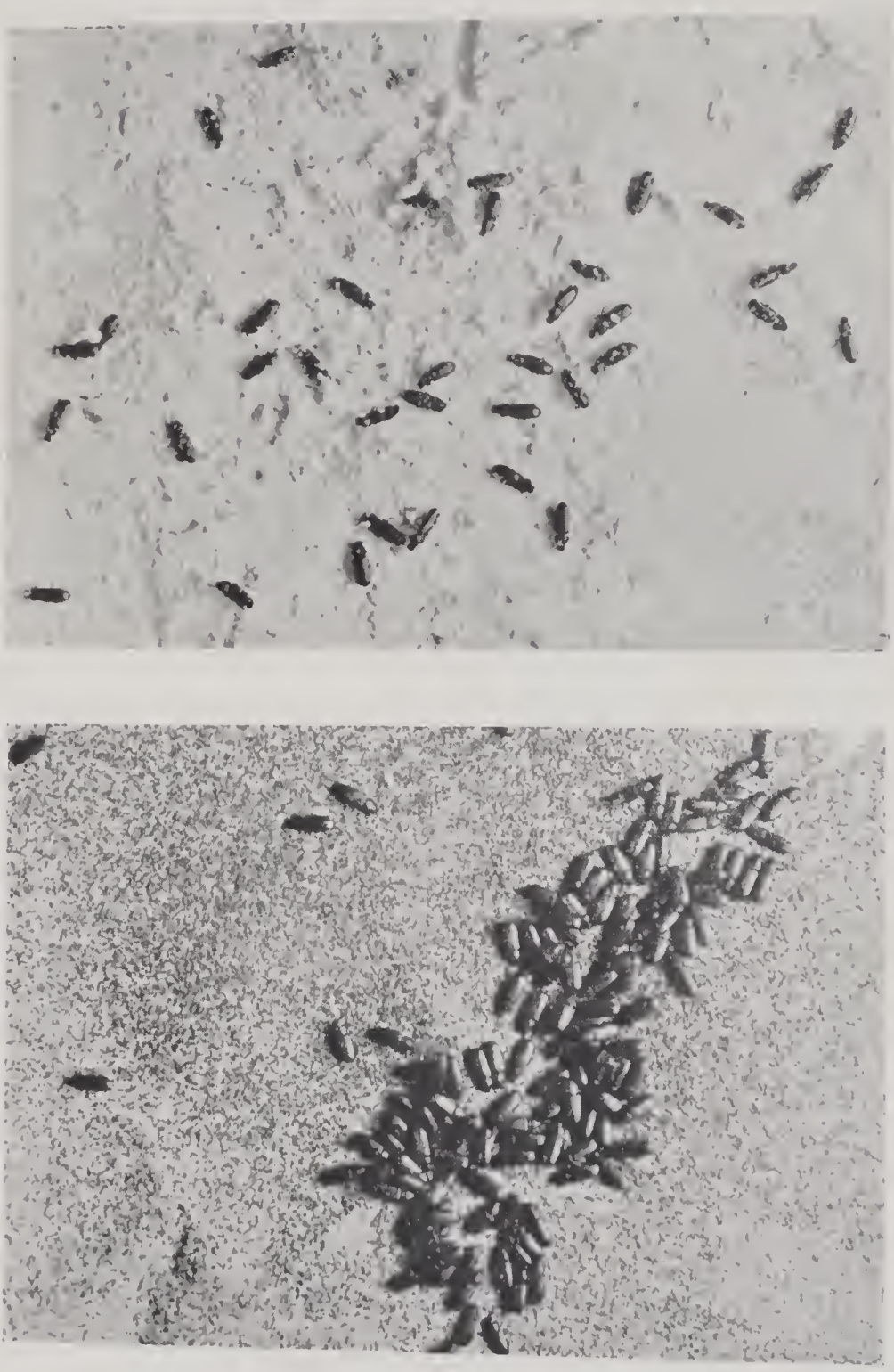

FIG. 4.—FLOUR BEETLES (*Tribolium*).

FIG. 5.—GRUBS OF FLOUR BEETLE.

FIG. 6.—SPIDER BEETLES (*Ptinus*).

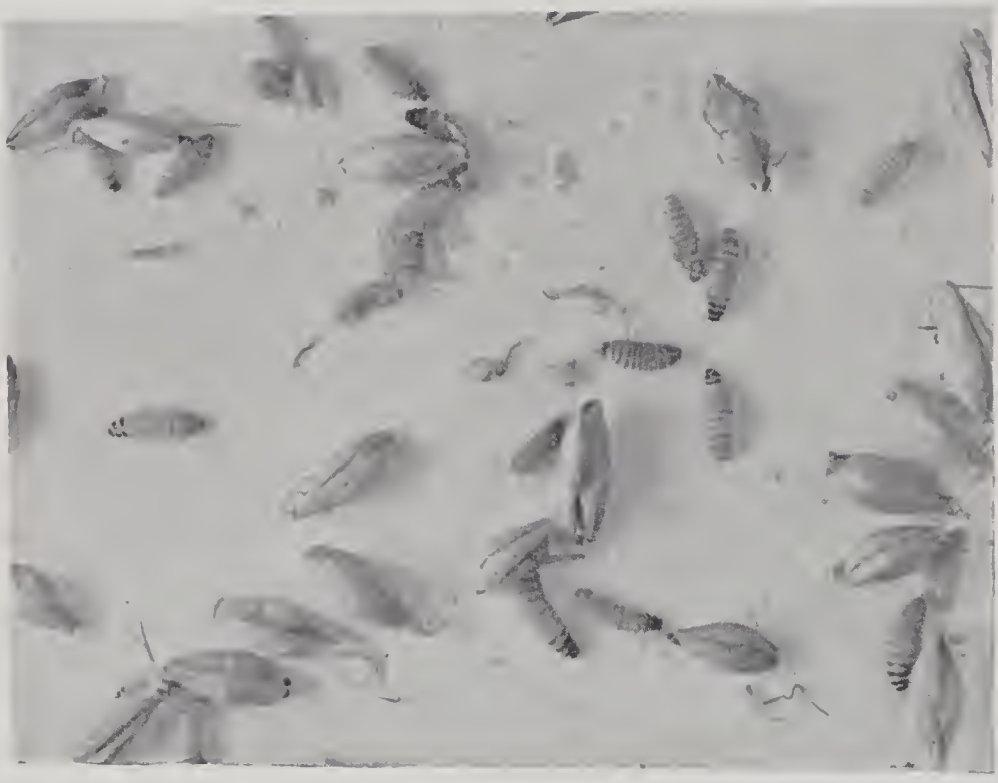

FIG. 7.—GRUBS OF KHAPRA BEETLE (*Trogoderma*).

FIG. 8.—KHAPRA BEETLE (*Trogoderma*).

FIG. 9.—WHITE-SHOULDERED MOTH (*Endrosis*).

FIG 10.—WHITE-SHOULDERED MOTH.
(*Endrosis.*)

FIG. 11.—SPECKLED OR SEED MOTH.
(*Borkhausenia.*)

cited are the moths of the genus *Tinea* and the " cacao-moth," *Ephestia elutella*.

Insects mentioned in this report belonging to other " orders " than the beetles and moths are various parasitic *Hymenoptera* or four-winged flies and the predacious bug *Lyctocoris campestris*. These insects prey upon beetles and their grubs and on the caterpillars of the moths. Their chief interest for us at the moment is that their occurrence in large numbers suggests an infestation of long standing.

Infestation by Mites

Combined infestation of grain by insects and by mites is usual, but observations made during the survey suggest that severe infestation by mites is a special phenomenon. These observations, which were most extensively made in western and north-western ports, confirm the findings of the late Professor Newstead, that severe infestation by mites or " mintiness," as it is called in some sections of the trade, is always accompanied, if it is not preceded, by deterioration of the grain, as a result of such biological causes as attack by insects and bacterial or fungal activity and the activity of enzymes " intrinsic to the wheat itself." Professor Newstead's findings, which are contained in the second and sixth reports of the Royal Society Grain Pests (War) Committee, so well described mite infestation that they deserve quotation.

> " It has become apparent during the past year that while mites may be found in wheat at all seasons, it is during the warm summer and autumn months that they are most plentiful and most likely to occur in detrimental numbers; this has also been the experience of the granary staff over a long period of years. Undoubtedly the summer temperature is the chief reason for this increase, but in the case of stored grain a second factor must be taken into account. In summer and autumn the stocks, harvested the previous autumn, have lain in bulk during transit and storage, and time enough has elapsed to allow any deteriorative processes due either to original inferiority or to bad conditions of transit and storage to spread throughout the parcel and become manifest. Chief among these deteriorative processes must be reckoned those due to bacterial activities or to enzymes intrinsic to the wheat itself, which bring in their train a large increase of moisture content and a rise of temperature. These processes if allowed to proceed unchecked may lead to intense " sweating " of the stock with a great rise of temperature (sometimes as high as 120° F.) and to ultimate rotting and putrefaction. It is at the commencement of this process, when the wheat is beginning to go " off," that mites generally occur in large quantities. We think it is improbable that they are the cause of the evil, but when present in large numbers they undoubtedly accelerate the deterioration."
>
> " The presence of mites in any quantity in grain may always be detected by the associated unpleasant and peculiar smell, known to the trade as ' minty ' or ' mitey '; when in very large quantities they may cause the grain to appear literally heaving; in less obvious quantities it is best to riddle some of the wheat in which mites are suspected and to examine the riddlings with a hand lens."
>
> " A great deal of uncertainty has prevailed heretofore with regard to the precise nature of the injury to grain resulting from mite infestation, and the fact that in former years the presence of mites was regarded as a guarantee of quality by millers is sufficient evidence of this. The objectionable smell which is associated with their presence in quantity must certainly be reckoned as detrimental. The granary staff also attribute to their activities the formation of a large amount of dust and dirt which hinders free ventilation between

the grains and so tends to promote the sweating evil. Apart altogether from these secondary effects of their presence, the fact that *Aleurobius*[1] actually devours the endosperm has to reckoned with; it must considerably impoverish the wheat."

* * * * * *

"Flour which is heavily mite-infested is certainly ruined. It has a most unpleasant odour and becomes much discoloured owing to the quantities of excrement with which it is charged. As a result of the infestation the moisture content increases and in the later stages moulds are found."

Whether the presence of mites is not still, in some quarters, regarded as an index of good quality is uncertain, but during the survey it was evident that it was used as a criterion by which the question of continued storage or immediate milling of grain was decided. In the light of Professor Newstead's findings, which have been confirmed, it is disconcerting to find that it is the opinion of some of the experts that "mintiness" is less an evil than a useful guide in determining whether the continued storage of a consignment is safe. In its advanced stages infestation by mites or mintiness is evidence of putrefaction, and it is worth recording that the odour described as "minty" resembled that of skatol, one of the less pleasant substances produced during the decay of organic matter. The problem of mintiness or infestation by mites urgently requires investigation, not only as a problem for the acarologist, or mite expert, but also as a biological problem of high importance to both the milling industry and the public, that needs to be tackled on broad physiological lines.

Fifteen kinds or species of mites occur on grain or flour or in grain stores. Of these the most important are the flour-mites, *Tyroglyphus farinae* De Geer (the *Aleurobius farinae* of Professor Newstead's report) and *Tyrophagus dimidiatus* Herm. The other species are either associates of these two or are predacious mites feeding on insects or on the flour-mites themselves.

PORTS

The port, as the centre for the distribution of grain and cereal products coming from overseas, is equally a centre for the distribution of any insects occurring in them (see Fig. 12). There is ample evidence of this, and it is noteworthy that insects which are not native to this country are found frequently by entomologists in warehouses at ports or in goods just delivered from them, and then, it may be years later, are found in warehouses inland, or even in the larders of private houses. What happens is that foreign insects gradually become established in the ports and from them spread and become established in the country generally. In so far as grain-infesting insects are concerned, it may truly be said that, while at one time a marked distinction might have been drawn between the kinds and numbers of insects found in the warehouses at the ports and those found in warehouses inland, that distinction is now of no importance.

Cereals and cereal products arriving at the ports may be distributed immediately, or they may be stored for a short period, or, as more frequently happens, grain may undergo treatment in the flour or provender mills which are now so marked a feature of the dockland landscape.

Transit Sheds

Goods remain in transit sheds only for short periods, not usually exceeding a fortnight. At all times a great variety of commodities is housed and, although

[1] Now called *Tyroglyphus*.

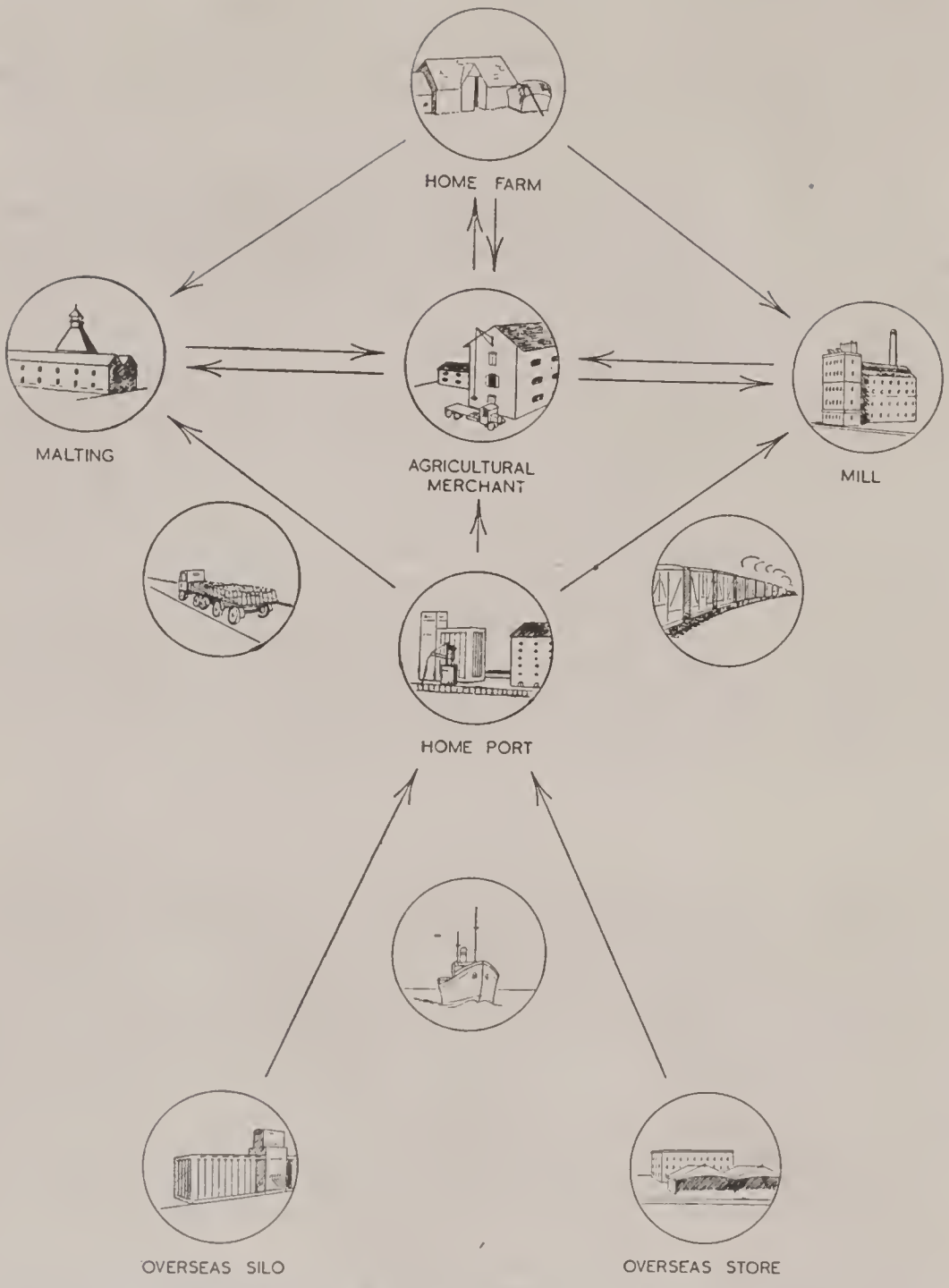

FIG. 12. *This diagram shows the complex nature of the movements of grain and grain products between the producer and the consumer. In any of these movements insects may be carried from one place to another, and at any of the points of contact cross-infestation may occur.*

they may remain there only for a very short time, there is every opportunity for a transference of insects from one commodity to another. For example, large numbers of copra-beetle (*Necrobia rufipes* De G.) were observed on ground-nut cake in one shed, and later it was found that some of them had crawled on to casks of tobacco and other commodities. In the same port all offals and meals were stored in the same shed. In this there were large quantities of badly infested goods, harbouring the spider-beetles, *Ptinus tectus* Boiel. and *Ptinus fur* L., the flour-beetle, *Tribolium castaneum* Hbst., and the moth *Tinea granella* L. It is certain that any goods placed in this shed, even for a short time, would become infested with these insects.

Transit sheds are generally so constructed that proper cleaning and disinfestation are difficult and, although the modern sheds are better in this respect, the constant influx of infested goods makes it difficult to keep them free from infestation. This can at present be done only by disinfestation of the goods before storage.

General Warehouses

Goods may lie in dock warehouses for varying periods of time, even for a number of years. Little is done, either by the public or the private warehousemen, to segregate various classes of goods (e.g., grain, offals, and manufactured feeding-stuffs), or to isolate infested consignments. The warehouses are usually congested with goods piled against the walls and with very little space between the stacks; this leads to difficulty in cleaning and hampers the receipt and issue of goods in any proper sequence. Goods may thus be overlooked and opportunity afforded for insects to multiply without disturbance. In a northern port, a warehouse was examined where goods, which had been stored for only a few days, were badly infested with the beetles *Tribolium castaneum, Ptinus tectus, Silvanus surinamensis* L., and the moths *Ephestia elutella* Hb. and *Borkhausenia pseudospretella* Stt. In this warehouse several sacks of maize-germ meal, Scots wheatfeed, and bran had been kept for two years, and were heavily infested with large numbers of these insects. Prolonged storage of these cereal products also leads to the rapid multiplication and spread of mites, which, once established, are very difficult to eradicate. In another warehouse in the same port the goods were stacked clear of the wall with plenty of space between, and sweeping was a daily routine; no rubbish, sweepings or old sacks were left lying about. Although the same classes of goods were stored here, no insects were found.

Many warehouses are old, ill-lit, and have wooden floors with numerous cracks and holes. Generally they have many years' accumulation of dirt and grain dust in which the resident population of insects maintains itself. Rats and mice break open sacks and packages and spill the contents. This leads to the accumulation of grain and cereal refuse round the stacks, and this may also be carried into the fabric of the building by rats and mice. The population of insects resident in general warehouses is similar to that found in bulk-grain warehouses and described below.

Granaries

(1) *Bulk-grain warehouses*

The grain in bulk-grain warehouses is stored on floors, being delivered by chutes after elevation to the top of the building. In contrast to storage in silos, the grain is stored so that its height above floor level varies from four to twenty feet, exposing a large surface. The grain is kept in place by bulkhead boards or by sacks filled with the grain.

The bulkhead boards have a large resident population of insects in the

cracks and holes in the wood and in the sacking joining them together. The commonest insects found here and also in the fabric of the buildings themselves are: *Calandra granaria* L. and *C. oryzae* L., the spider-beetles, *Ptinus tectus* Boiel. and *Niptus hololeucus* Fald., the beetles *Attagenus pellio* L. and *Tenebrio molitor* L., and the moths *Borkhausenia pseudospretella* Stt., *Endrosis lacteella* Schiff., and *Ephestia elutella* Hb. Bulkhead boards are used repeatedly without any cleaning. The spaces between the sacks filled with grain that are used to keep the pile in place are a favourite hiding-place for many insects, especially the beetles *Ptinus tectus, Tribolium castaneum, Tribolium confusum* Duv., *Calandra granaria, Calandra oryzae,* and *Tenebrioides mauritanicus.*

Insects can maintain themselves in the fabric of a building for a long time. This is especially true of the spider-beetle *Ptinus tectus,* which are often found in empty warehouses and are capable of maintaining themselves for a considerable time at a low level of numbers and rapidly multiplying when given another supply of suitable foodstuffs. These beetles are found in large numbers in bulked grain only when it is stored on floors.

Where a large surface of grain is exposed, the outer layers tend to become very moist, thereby providing excellent conditions for the multiplication of insects. Such conditions are also favourable for the rapid development of mites. Usually no facilities exist in bulk-grain warehouses either for screening or for turning grain which has become heated owing to the presence of insects or mites and, as there are no means of segregating infested grain, one badly infested consignment introduced into a warehouse may lead to infestation of all other grain in store.

There is rarely any cleaning beyond an occasional sweeping, and these warehouses are usually very dusty and dirty, with the windows covered with old cobwebs. The warehouses of one port authority in the north-west of England are regularly cleaned by a powerful vacuum-cleaner fitted with attachments for cleaning the ceilings and walls. Although this is effective in removing loose dust or grains and undoubtedly reduces infestation, it does not dislodge insects or cocoons lying in cracks or crevices.

(2) *Silos*

In silos the grain is stored in bins of various capacities, up to about 250 tons; all bins, with the exception of chimney-bins, extend for the whole height of the silo, and have the common characteristic that the depth is much greater than the cross-section; the surface exposed is, therefore, small. The grain is elevated, and after passing over screens and being aspirated to remove foreign materials, such as small stones, sand, and dust, is carried on conveyor-bands and discharged into a manhole in the top of the bin. This manhole is kept covered, except when the grain requires ventilation. There is very little chance for insects to travel by their own efforts from one bin to another, and an infested consignment is automatically segregated when once in the bin, except in wooden silos in which the tops of the bins are covered by a false floor. Occasionally, however, insects are thrown off the conveyor-bands, together with light dust, and may find their way into a bin. This is especially true of bins at the end of a band's travel.

Most of the modern silos are equipped with built-in thermometers at various depths in the bins, by means of which the condition of the grain is checked daily. In the older silos the temperatures are taken by means of hand-operated spear-thermometers which penetrate the grain only to a depth of about 20 feet at the most. Similar spear-thermometers are used in bulk-grain warehouses. Grain which is found to be heating can be readily turned or revolved and, if necessary, can be screened to remove insects. It should, however, be noted that screening will remove only free-living insects and the adults, but not the

egg, grubs, or caterpillars of those which develop within the grain in the immature stages (e.g., the weevil *Calandra* and the moth *Sitotroga*).

The more recently constructed silos are built of concrete, which provides a smooth surface on the inside of the bin. The older silos are constructed of brick or wood; laminated-wood silos are common in flour mills. The walls of these brick and wood bins provide innumerable cracks and crevices in which grain and insects are lodged. It is possible for a resident population to maintain itself for a very long time by feeding on this grain. In a very exposed northern port, some bins in a wooden silo which had been empty for ten to twelve months, and had previously held Plate and African maize, contained large numbers of live beetles—namely, *Calandra granaria, C. oryzae, Tribolium castaneum, Silvanus surinamensis, Rhizopertha dominica* F., *Tenebrioides mauritanicus*, and two species of *Laemophlaeus*. The cleaning of brick and wooden bins is much more difficult than that of concrete bins, which are said to be self-cleaning. Except for the use of long-handled brushes, operated from the top and the bottom of the bin, no regular cleaning of any type of bin was seen.

The constant working of grain through the top floor of the silo throws up large quantities of dust in which all stages of insects and mites are present. This dust is swept up at intervals; it may be removed by suction-traps in the floors of modern silos, but, although it seems incredible, is more often swept into the most convenient bin.

The following data, obtained from the examination of the various consignments in the port warehouses and granaries seen during the survey, indicate the extent and nature of the infestation under the three main methods of storage. Of 3,316 consignments seen, 46 per cent. were infested, mainly with *Calandra* weevils, the next most important insect being the beetle *Ptinus tectus*. The infestation was distributed as follows; silos 31 per cent., bagged grain 59 per cent., and bulk grain 75 per cent. In the general warehouses at the ports, 65 per cent. of the consignments of feeding-stuffs were infested, and in mill warehouses 60 per cent.

At the ports, as the evidence of the survey shows, the grain-weevils account for the greatest part of the infestation of consignments from all countries except India. When it is remembered that these weevils are primary pests and lay the grain open to attack by insects of secondary importance, the damage done by weevils at the ports is evidently serious. It is worth noting that in modern silos, properly managed, infestation may be low. The main sources of infestation are Indian rice-bran and Australian wheat, both of which are badly infested on arrival.

TRANSPORT

To deal adequately with the part played by the vehicles of transport in bringing insects that infest grain into this country and distributing them, it is desirable, if not essential, that the conditions of infestation and its development during oversea transport should be investigated. That work is beyond the scope of the survey, and the information now given about the part played by sea-going vessels in introducing new, and augmenting existing, populations of insects in our warehouses, mills, and farms, is based on examination of ships lying at the ports and of newly landed cargoes.

Four types of ship bring grain and cereal products to the ports: large cargo-boats, specially designed to carry grain as the sole cargo; the cargo-boat or tramp, carrying grain as part cargo with other goods; the liner, carrying small amounts of grain and cereal products as part of the general cargo; and the sailing ship, which is fast disappearing, bringing grain from Australia as its sole cargo.

The greater part of the grain arrives in this country as the cargo, in whole or in part, of a ship of one of the first two classes. On the outward journey these ships may carry any kind of goods, but the usual cargo is coal.

The small coastal tramp is used to tranship grain from continental ports or to receive part of a large cargo in one of the British ports for delivery to another part of the coast. Such vessels often carry several small parcels of grain, in addition to flour, offals, and feeding-stuffs, and there is thus every opportunity on them for grain and cereal products to become cross-infested.

Ships do not carry any one class of grain from any particular country. For example, a ship may carry Plate maize on one voyage and Manitoba wheat on the next. Offals and whole grain are often carried together. Most ships from the Plate bring not only wheat but also pollards and middlings; the latter are often stored in bags on the surface of the bulked grain. Liners from South Africa generally bring a mixed cargo of maize, hominy chop, maize-meal, and often hides as well in the same holds.

After discharge the ship is swept out to clear the bottom of the hold. This sweeping is not designed to do anything more than remove general rubbish and dust, and is often perfunctory. In a number of ships layers of coal and grain have been found on girders in the more inaccessible parts of the holds where cleaning has been neglected, and in the sides of the holds and bulkheads, accumulations of grain, dust, and rubbish which have been there for several voyages. Such accumulations provide places in which weevils and other insects shelter and breed until such time as another cargo is loaded, which they can then infest. A small coaster was inspected in which several beetles[1] were found some three weeks after a cargo of infested wheat sweepings had been carried from the continent. It was claimed that this boat was swept out regularly, and it had actually made six voyages since the sweepings had been unloaded. Accordingly, any grain or cereal products carried in the ship during that period would almost certainly have been infested. This infestation, however, might not become evident until several months afterwards when the insects had bred in sufficient numbers to damage the whole consignment. Weevils and many other pests of grain are able to maintain themselves in a ship for considerably longer periods than three weeks, so that if the ship brings infested wheat into this country and takes back coal, the next lot of grain brought over may arrive infested, although it may have been free from insects when loaded in the exporting country.

Transhipments are frequently made to our ports, either from the continent or from another part of the British coast. Ships bring grain from overseas into one of the continental ports, and, on arrival there, part of the cargo, owned by or consigned to an English merchant or miller, is then loaded into one of the coastal tramps and brought across to this country. The grain may be discharged into the tramp directly, or may be discharged ashore and temporarily stored until transport can be obtained. This temporary storage is often carried out in lighters and barges. Grain transhipped from port to port in this country may be sold by one merchant to another soon after arrival, or after storage in a warehouse. There is much risk of cross-infestation taking place if the coaster, barge, or lighter has not been properly cleaned, or if the cargo is stored in an infested warehouse. For this reason grain which is transhipped is more often infested than grain shipped directly.

The kinds and numbers of insects present on goods in ships depend on the nature of the goods and the country of their origin. A table based on an analysis of all the ships examined and showing the kinds of infestation found will be found at the end of this section.

The fact that insects are found in large numbers on the grain and cereal

[1] *Calandra oryzae, Tribolium castaneum,* and species of *Laemophlaeus.*

products before discharge is proof that these insects are coming from abroad with the grain.

Distribution from the ports is carried out by road, rail, and water (see Fig. 12). All classes of grain are carried in these ways, including not only the whole grain but also the products of the manufacturing sections of the industry.

Large quantities of whole grain, both in bulk and in sacks, flour, and feeding-stuffs are carried in barges on canals and rivers. Several barges were examined, and from the variety of sweepings in the bottoms of the holds it would seem that efficient cleaning is difficult. The use of barges for the carriage of all classes of goods, without proper cleaning, leads often to cross-infestation. For example, flour in sacks was being loaded into a barge from which infested wheat had shortly been discharged to a riverside mill.

Railway transport falls into two classes, that within the docks and main-line traffic.

Vehicles are often set aside for the carriage of goods to and fro in the dock estates. Vans and trucks for such work usually remain within the docks and are not used for long hauls. There does not appear to be a sufficiently regular cleaning or segregation of wagons which may frequently have to carry infested goods. In a west-coast port trucks, which had been used on the previous run for the carriage of rice-bran, well known as " lousy meal," were being loaded with malting barley in sacks. The types of vehicles used for local work in the docks are old open wagons and box-vans and special bulk-grain vans.

Grain and cereal products are carried from place to place on the main lines in open wagons, closed box-vans, bulk-grain vans and containers, all of which may be constructed partly or wholly of wood or metal. Most of the vehicles are owned by the railways and fall into the " common user " class, but there are also a number of privately owned vehicles, especially bulk-grain vans. The railways also own large numbers of lorries of all types.

In addition to acting as carriers, the railways also warehouse goods. For this purpose they have large buildings in the principal towns and smaller warehouses in most goods yards. As well as being used for goods in transit, rooms in warehouses are often let to grain and agricultural merchants and flour millers and provender millers, especially the makers of branded feeding-stuffs. Space is also allowed for the storage of hired grain sacks.

The railways own and control the whole system of docks at certain ports—for example, Hull and Southampton.

The types of road transport fall into two main classes, both of which usually carry out their operations outside the docks. The functions of general hauliers are similar to those of the main-line railways in carrying and warehousing, with the exception that they are not " common carriers." Rural carriers often operate a service for the transport of milk to the principal towns, and their lorries usually return with a load of feeding-stuffs for the farmers supplying the milk. Lorries are used by the railways for distributing goods in the neighbourhood of goods depots, but there are also a few medium-distance routes served by them.

Agricultural merchants use their vehicles not only for the carriage of feeding-stuffs from their warehouses to farms and for bringing back grain, but also for the transport of feeding-stuffs from port warehouses, mills, and railway depots direct to farmers and to their own warehouses.

Farmers rely on the agricultural merchants' transport for the delivery of goods, but many use small trailers for carrying small quantities of feeding-stuffs about the farm and also from the warehouses of agricultural merchants, mills, and railways. Large farms often have their own lorries. Unthreshed grain is carried from the fields in carts, and the threshed grain may occasionally be taken in these carts to the corn merchant or mill.

Brewers and distillers rarely rely upon their own transport for the supply of grain. Most of it is carried either direct from the port or farm by grain merchants' lorries or by the railways.

As most of the large mills are built on the dock-side, it is only those with no direct communication by rail or water that use lorries. Whilst much grain is carried in hired sacks, several types of bulk-grain lorry have been examined. The most simple form consists of a modification of the standard flour lorry, which is fitted with a wood or steel box body with hopped bottom. These lorries carry about 20 tons of wheat, and in the principal Scottish ports lorries of this type may be seen running every day between the silos and the mills. A more specialized type is the steel bulk-grain articulated lorry, which will carry about 40 tons of grain in several separate compartments. Different types of grain can be carried at one time. These vehicles transport grain for greater distances than the other types, and are used regularly between Liverpool and Warrington and Glasgow and Paisley.

The principal use of the lorry by mills is for the distribution of flour in sacks direct to bakers, and of offals and feeding-stuffs to depots and agricultural merchants' warehouses. Empty sacks are collected as new lots of flour are delivered. Insects from these sacks may move on to other goods still on the lorry, and thus infest goods which may have left the mill clear of infestation. These movements of grain and produce are shown in diagrammatic form in Fig. 12 (p. 10).

It is certain that at least a small number of insects will remain in any vehicle that has carried infested goods. All wooden railway and road vehicles have space between the floorboards and cracks and crevices in the walls in which meal and grain collect. Insects can feed and breed there in the same way as in the fabric of warehouses. For example, a lorry owned by one of the large flour millers, and engaged in the delivery of grain and flour, was found to have a considerable quantity of odd grains and meal on the floor. There were a number of beetles (*Calandra oryzae* and *Rhizopertha dominica*) amongst the grains. The driver stated that the lorry was washed down once a week, if time could be found, but that it was never brushed between loads.

An example of the way in which insects from an infested lorry might have done considerable damage was given by a farmer in South-West England, who has no cattle and hence buys no feeding-stuffs. The grain is stored, after being dried, in a large well-built concrete-floored barn set in the middle of the fields. A corn merchant had sent his lorry to collect a consignment of grain, and as the lorry was backing to the loading platform the farmer noticed that it was crawling with weevils. He forced the driver to sweep out the lorry, well away from the barn, before he permitted him to load the grain. If this farmer had not observed the insects, they might not only have infested that particular consignment but also have invaded the barn and infested a large stock of malting barley.

Railway companies, as common carriers, are obliged (with minor exceptions) to transport, but not necessarily to warehouse, all goods offered to them. It is certain that grain, cereal products, and feeding-stuffs are, as a class, among the goods most heavily infested by insects and mites which they handle; others are bones, hides, and wool. The insects, however, may drop off or wander from the goods in which they were originally living, and, as stated above, often remain in the vehicles. If the vehicles are used again without having been cleaned, the insects may find their way on to human foodstuffs and other classes of valuable goods on which the mere presence of insects causes considerable loss to the owners, mainly through injury to their prestige. Insects find their way all over warehouses, and railway companies have had claims for damage due to insects moving from infested feeding-stuffs on to other commodities, such as

flour and boxwood for making chocolate boxes. A list of insects found in the warehouses of one of the railway companies has recently been published.[1]

Farmers have made claims against the railways for compensation for loss of value in malting barley refused by the maltster because of the presence of weevils. The farmer has then accused the railway company of supplying insect-infested sacks or of carrying the barley in infested vans or wagons. It has, however, been shown that much of the infestation of home-grown grain occurs before it leaves the farm, during storage in infested buildings. To reduce the number of claims made against them, the railway companies have developed a system of control.

At the ports and principal distributing centres where the railways have their own warehouses, infested cereals and cereal products are housed in warehouses set apart for them. These are sometimes frankly referred to as " weevil " warehouses. All goods are examined before they are accepted for carriage or warehousing, and if insects are found the fact is notified to the goods agent at the destination, who is instructed to refuse to warehouse the goods unless he has a special " weevil " warehouse, and to press the consignee to accept immediate delivery. To assist railwaymen in the recognition of the common pests, one of the main-line railways has issued a book of instructions and a wall chart with illustrations, and the men handling suspected goods are very adept at " spotting " insects.

After the infested consignment has been unloaded, the wagons or vans are examined. Wagons are sent to the nearest cleansing depot for a thorough hosing and for treatment with an insecticide. Vans are sent to main depots, where they are swept and sprayed with insecticides, and one railway company has built a special chamber in which vehicles are subjected to treatment by heat or fumigation. The wagons and vans are then returned to service. While the railway companies cleanse their own vehicles, they have no power to clean privately owned vehicles. In Scotland, for example, much infested grain, especially South African maize and distilling barley, is transported in privately owned bulk-grain vans, which are only occasionally swept.

Treatment of wagons and vans by heat or by fumigants in a special chamber is effective when sufficient time is allowed . It proved difficult, however, to assess the efficacy of the other measures used in disinfesting rolling stock.

The cleansing of wagons by hosing does not mean that they are disinfested or wholly freed from insects, since insects were found on several occasions to survive both hosing and spraying. The spraying was sometimes little more than sprinkling. No opinion can be offered of the value of the insecticides used. Some of them are proprietary insecticides, and their constitution or composition is not known. Other materials used are primarily disinfectants, and it may be opportune to say that, contrary to common opinion, effective disinfectants, or, more properly, bactericides, are not always insecticidal. It is evident that the devising of efficient insecticides for the disinfestation of rolling stock deserves early investigation.

Although a rigorous system of control of infestation is applied to the rail and road vehicles owned by the railway companies, no evidence was found in the survey of anything similar in any other sections of the inland-transport industry.

[1] H. Hayhurst, *Annals of Applied Biology*, 1937, **24**, 797.

Details of the Infestation of Cereals and Cereal Products Found in Ships' Cargoes

U.S.A. (CALIFORNIA)	
Malting barley in bags	Fair numbers *Calandra granaria, Tenebrioides mauritanicus,* and *Sitotroga cerealella.*
Barley in bulk	Small numbers *Corticaria* sp., *Enicmus minutus, Omosita colae, Sitona flavescens, Anthicus floralis, Glyphicnemus* sp., *Pterodela pedicularia,* and *Lyctocoris campestris.*
Malting barley in bags	Fair numbers *Calandra granaria*; also sp. *Cantharis livida* and *Ophonus brevicollis.*
U.S.A. (other than California)	
Maize in bulk	Clear of insects.
Maize in bulk	Clear of insects.
Maize in bulk	Clear of insects.
RIVER PLATE	
Plate bran in bags	Small numbers of *Pyralis farinalis, Ephestia elutella, Tribolium confusum, Tenebrioides mauritanicus* (adults and larvæ), *Silvanus* spp.
Pollards in bags	Few *Tenebrioides mauritanicus.*
Middlings in bags	Few *Tenebrioides mauritanicus, Ephestia elutella,* and *Carpophilus hemipterus.*
Maize in bulk	Clear of insects.
Wheat in bulk	A few *Sitotroga cerealella.*
Bran in bags on top of wheat	Fair numbers *Tenebrioides mauritanicus* (adults and larvæ), *Plodia interpunctella,* and *Calandra oryzae.*
Maize in bulk	Large numbers of *Sitotroga cerealella* and *Calandra oryzae.*
Maize in bulk	Heavy infestation of *Calandra oryzae, Sitotroga cerealella,* and *Lepisma* sp.
Wheat in bulk (transhipped in Hamburg)	Small numbers dead *Calandra granaria, Calandra oryzae*; large numbers live *Tribolium confusum,* and also *Cryptophagus* sp. and *Cercyon terminatus.*
Maize in bags	Fair numbers *Calandra granaria, Calandra oryzae,* and *Sitotroga cerealella.*
Bran in bags	Clear of insects.
Semeten in bags	Clear of insects.
Wheat-germ in bags	Good numbers of *Calandra granaria, Tinea granella, Tribolium castaneum,* and *Tribolium confusum.*
Maize in sacks and bulk	A few *Calandra granaria*; fair numbers *Calandra oryzae,* and a few *Tribolium castaneum.*

BRAZIL

Wheat-germ in sacks	Good numbers of *Calandra granaria, Tinea granella, Tribolium castaneum,* and *Tribolium confusum.*

AUSTRALIA

Wheat in bags	Large numbers *Calandra granaria, Calandra oryzae, Sitotroga cerealella,* and also a few *Ephestia elutella.*
Wheat in bulk	A few *Calandra oryzae, Lyctocoris campestris, Tenebrioides mauritanicus, Enicmus histrio,* and *Cryptophagus* sp.
Wheat in bulk	A few *Ophonus brevicollis* and *Enicmus histrio.*
Wheat in bags (barge ex ship)	A few *Calandra granaria, Silvanus surinamensis,* and *Tribolium* sp.
Wheat in sacks (barge ex ship)	A few *Calandra granaria, Silvanus surinamensis, Tribolium castaneum,* and *Rhizopertha dominica.*
Wheat in bags (ex sailing ship)	Fair numbers *Calandra granaria, Tribolium castaneum, Lariophagus distinguendus,* and undetermined *Lepidopterus* larvæ.

NEW GUINEA

Copra in bags, also remains of previous wheat cargo	Large numbers *Dermestes cadaverinus, Necrobia rufipes, Calandra oryzae, Tribolium castaneum, Silvanus* spp., *Ephestia elutella, Sitotroga cerealella, Plodia interpunctella, Corcyra cephalonica, Plochionus pallens,* and *Cryptophagus* sp.
Flour in barrel in ship's store	Large numbers *Tribolium castaneum, Tenebrioides mauritanicus* (larvæ), *Caenocorse ratzeburgi, Necrobia rufipes,* and *Dermestes cadaverinus.*

BURMA

Kibbled rice in bags	Large numbers of *Tribolium castaneum, Ephestia elutella, Tenebrioides mauritanicus,* and a few *Trogoderma khapra.*
Ground-nut cake in bags	Very large numbers *Trogoderma khapra*; large numbers *Corcyra cephalonica, Ephestia elutella, Alphitobius diaperinus, Tenebrioides mauritanicus, Laemophlaeus* sp. and a few *Amphibolus venator.*
Wax in bags	Fair numbers *Ephestia elutella* and *Tribolium castaneum.*
Rice-bran in bags	Fair numbers *Tribolium castaneum* and *Ephestia elutella.*

Kibbled rice in bags	Fair numbers *Ephestia elutella, Corcyra cephalonica, Laemophlaeus* sp., *Alphitobius diaperinus, Silvanus* sp., *Tribolium castaneum, Tenebrioides mauritanicus, Caenocorse ratzeburgi, Calandra oryzae, Tribolium confusum,* undetermined Mites and *Periplaneta americana.*
Linseed-cake in bags	Large numbers *Tribolium castaneum.*
INDIA	
Karachi wheat (old crop) in bags	Very large numbers *Trogoderma khapra*; large numbers *Ephestia elutella, Tribolium confusum,* and *Rhizopertha dominica.*
Karachi wheat (new crop) in bags	Fair numbers *Tribolium confusum.*
Ground-nut meal in bags	Very large numbers *Tribolium confusum* and *Ephestia elutella.*
Linseed in bags	Numbers of *Trogoderma khapra* and *Tribolium confusum.*
Rape-seed in bags	Clear of insects.
Wheat in bags (new crop)	Clear of insects.
Barley in bags (new crop)	Some *Tribolium castaneum, Rhizopertha dominica,* and *Trogoderma khapra.*
Wheat in bulk (transhipped from Rotterdam)	Clear of insects.
Wheat sweepings (transhipped from Antwerp)	Large numbers *Calandra oryzae, Tribolium castaneum, Laemophlaeus* sp., *Lariophagus distinguendus, Piezostethus flavipes, Lyctocoris campestris, Chaetospila elegans, Cephalonomia westwoodi Plastanoxus waterstoni.*
IRAN	
Barley in bulk	A few dead *Sitotroga cerealella.*
RUSSIA	
Wheat in bags	Clear of insects.
Bran in bags	Clear of insects.
Middlings in bags	Clear of insects.
Barley in bulk	Fair numbers *Psocids* and Mites.
Wheat in bulk	Large numbers *Tribolium confusum, Calandra granaria, Tenebrioides mauritanicus* (larvæ), and *Psocids.*
Barley in bulk	Fair numbers *Calandra granaria, Psocids,* and dead *Eurygaster* sp. (" Wheat Bug ").
ROUMANIA	
Wheat in bulk	Large numbers *Calandra granaria, Laemophlaeus* sp., *Silvanus surinamensis, Tribolium castaneum, Tribolium confusum, Sitotroga cerealella, Tenebrio molitor,* and *Lariophagus distinguendus.*

Wheat in bulk	Large numbers *Calandra granaria*, *Lariophagus distinguendus*, and *Silvanus surinamensis*.

SOUTH AFRICA

Maize-meal in bags	Clear of insects.
Hominy chop in bags	Clear of insects.
Maize-meal in bags	Clear of insects.
Maize-meal in bags	Clear of insects.
Crushed maize in bags	Clear of insects.
Maize in bulk	Large numbers *Calandra oryzae*, *Silvanus surinamensis*, *Tribolium* sp., *Lariophagus distinguendus*, *Sitotroga cerealella*, *Ephestia kühniella*, and *Plodia interpunctella*.
Maize-meal in bags	Clear of insects.

CANADA

No. 3 N. Manitoba wheat in bulk	Clear of insects.
Amber Durum wheat in bulk	A few *Calandra granaria* and *Tenebrioides mauritanicus*.
Manitoba wheat (spring) in bulk (transhipment)	Clear of insects.
Manitoba wheat in bulk (barge ex ship)	Clear of insects.
Manitoba wheat in bulk	A few *Ophonus brevicollis*, *Enicmus minutus*, and *Anthicus florallis*.
Manitoba wheat in bulk	A few *Plodia interpunctella* and small *Diptera*.
C.W. barley in bulk	Clear of insects.
Manitoba wheat in bulk	Clear of insects.
Bran in bags; pinhead oatmeal in bags; flour in bags	Clear of insects.

SACKS

Millions of sacks are used annually for the storage and carriage of grain, cereal products and feeding-stuffs. They fall into three classes:—

(1) Closely woven sacks
- Hired grain sacks
- Imported grain sacks
- Flour sacks
- Offal bags
- Farmers' grain bags

(2) Openly woven sacks
- Offal bags
- Feeding-stuffs bags
- Wrappings of oilcakes

(Certain types of these bags may have a paper lining; these are to be distinguished from the next class.)

(3) Paper sacks
- Flour sacks
- Offal bags
- Meal and poultry-food bags

Grain pests cannot breed on the materials of which the sacks are made; they are, however, able to survive for considerable periods in empty sacks on small quantities of grain and meals left in them, and even, if the temperature is low, to survive without food for a long time. Some idea of the quantity of grain and meals left in empty sacks is shown by the fact that the grain extracted in a year at one of the larger railway sack depots is worth £60 to £80.

The great bulk of the grain in this country is transported in sacks hired for the purpose from one of the sack-hiring companies or the railways. These sacks are supposed to be used solely for the carriage of whole grain, but they have frequently been seen in use for offals and feeding-stuffs. A number of the millers and many agricultural merchants have their own sacks for this purpose. After each hire the sacks are returned to the nearest depot, often in railway stations or agricultural merchants' warehouses. The infestation of railway warehouses has already been described and that of agricultural merchants' premises is discussed later. At the depots the sacks are examined and turned, and if reasonably clean they are reissued for further use. The railway companies have issued strict instructions that any sacks which have carried infested goods must be returned to a central depot for cleaning. The private sack hirers do not appear to have any such regulation. The normal methods of cleaning are shaking and hand brushing, but at the central depots suction cleaners and beaters are also used. Tests made with one of these suction cleaners showed that they will not remove all the weevils (*Calandra granaria*), which have the power of clinging very firmly to the jute fibres. The same applies to many other insects and to mites. Even if these free insects were removed by them, no suction machines can remove insects or grain from the turnover at the bottom of the sack, and for this reason sacks are often issued in an infested condition. A farmer in Buckinghamshire received from a local depot a number of sacks which were so heavily infested with spider-beetles (*Ptinus tectus*) that he was obliged to treat them in a steam chest and brush them all before use. The railway companies have to take particular care, since the alleged infestation of grain from infested sacks has been the grounds for many claims, especially in the trade in malting barley. Even though sacks may have carried clean grain and have been emptied outside the warehouse, they may be infested by coming into contact with infested goods. Sacks of Scotch barley which were quite free of insects when taken to a Highland distillery by coastal steamer were returned empty in the ship together with sacks of dried grains which were heavily infested with *Calandra granaria*.

Another type of sack which travels to and fro is the flour sack. As already mentioned, the millers clean their flour sacks on return in suction cleaners or beaters, and remove large quantities of flour and dust. Insects, especially the moths *Ephestia kühniella* and *Endrosis lacteella*, and the beetles *Tribolium castaneum*, *Tenebrioides mauritanicus*, *Ptinus tectus*, and *Tenebrio molitor*, are often found on these sacks, and the normal methods of cleaning remove all except cocoons. The cost of cleaning and the possibility of insects being brought into the mills have led one of the big Scottish flour millers to use non-returnable flour sacks. He stated that since their introduction the intensity of mill-moth infestation had been appreciably reduced.

There is a considerable trade in second-hand bags, which are used for the carriage of feeding-stuffs and farmers' grain. That these sacks spread insects was shown in a north-country port where the bags from a cargo of Australian wheat were found to have a number of weevils in them. The sacks had been purchased by a provender miller for the packing of meals. The use of second-hand bags also plays a great part in the distribution of mites.

The insects found on piles of sacks in depots vary according to the degree of infestation of the premises concerned. The numbers of insects found on sacks

in agricultural merchants' premises is very high. The following were found in considerable numbers on sacks in a Middlesex agricultural merchants' warehouse: *Ptinus tectus*, *Sitodrepa panicea* (the " biscuit weevil "), *Tribolium castaneum*, *Silvanus surinamensis*, and species of *Tenebrio*. Where the sacks are stored in separate warehouses the numbers of insects are usually much lower, but even there a large variety of insects have been found. In a railway sack warehouse in Scotland the following beetles were found on a pile of sacks which had been in store for some five months: *Niptus hololeucus*, *Tribolium castaneum*, and *Eurostus hilleri*. In a large central sack-company's depot in the south of England large numbers of *Calandra granaria*, *Tribolium castaneum*, *Tribolium confusum*, and *Ephestia elutella* were found. The general state of cleanliness of the store was very low. Piles of old sacks in any premises form ideal breeding-places for insects, and it is the common practice of warehousemen to lay down a damp sack for the trapping of weevils and the breeding of meal-worms (the grubs of *Tenebrio molitor*). In the examination of buildings special care was taken to examine all piles of sacks, since many insects were often found there when not seen in other parts of the building. The insects most commonly found under sacks are the beetles *Ptinus tectus*, *Niptus hololeucus*, *Tenebrio molitor*, *Tenebrio obscurus*, *Trigonogenius globulum*, *Calandra granaria*, *Tenebrioides mauritanicus*, species of *Cryptophagus*, and the moths *Borkhausenia pseudospretella* and *Endrosis lacteella*.

The heavy grain and flour sacks are so closely woven that insects find it very difficult or impossible to enter them except where they are tied at the top. Certain insects, such as *Ptinus tectus*, *Ptinus fur*, *Tenebrioides mauritanicus*, and *Endrosis lacteella*, however, are able to bore their way between the fibres. The more openly woven meal sacks are readily penetrated by insects, and the activity of *Tribolium castaneum* in spilling the contents of rice-bran and flour sacks is well known. For example, one provender miller estimated the loss in weight to amount to as much as 5 per cent. Openly woven sacks, such as those used for flaked maize, brewers' grains, and many nuts for feeding animals, afford the contents no protection from invasion by insects.

Paper sacks are smooth and insects find great difficulty in clinging to their surfaces. The sacks are generally used only once and are destroyed when empty. It would therefore seem that their extended use would go a long way to reduce infestation.

MILLS AND AGRICULTURAL MERCHANTS' PREMISES

There is a tendency at the present time to concentrate flour and provender milling at the ports. Many of the modern mills are built in the docks, so that ships can discharge their cargoes direct into the mill's silos and warehouses, but such mills also draw supplies of grain and other raw materials from public warehouses. There are still numbers of flour and provender mills inland, and they usually have ready access to railways, rivers, or canals. The larger inland flour mills are found in those parts of England where there are readily available supplies of home-grown wheat of milling quality.

Flour mills

Fifteen flour mills were visited, of which two were in Scotland, four in Northern England, and nine in Southern England.

All large mills store grain in silos, which are of the types already described in the section on ports. The grain is screened and aspirated before storage. Mixed grains (e.g., dry Australian and damp English wheats) are stored in conditioning bins. There is here the possibility of cross-infestation taking

place, and if the grain is stored for a considerable time much damage may be done. It is not the practice of millers to store their grain for more than two months, but where a particular wheat can be included only in small quantities in the grist and can be obtained only during a short period of the year it may be necessary to store it for a considerable time.

The normal processes of preparing grain for milling remove all free adult and larval insects, but eggs and immature insects inside, or attached to, the grain are not removed. Insects are found in the machinery from the feed to the second " break " to the stage when the separation of flour and offals is almost complete. In particular, infestation was found to be greatest in the machinery of the reduction process. The insects causing it live in the masses of webbed material that is spun by larvæ of the mill-moth, *Ephestia kühniella*. It appears that the webbing is caused by caterpillars hatching out and developing in small accumulations of flour and offals, lodged where there is a change in speed or direction of the milling stream, at the bottoms of elevator boots, in worm conveyors and reel hoppers. Modern milling machinery has reduced the opportunities for insects to develop in it, but more remains to be done in the improvement of design to this end. Insects found in the webbing, in addition to the caterpillars of the mill-moth, *Ephestia kühniella*, include the beetles *Gnathocerus cornutus* and *Gnathocerus maxillosus*, *Laemophlaeus ferrugineus* and *Laemophlaeus minutus*, *Tribolium confusum* and *Tenebrioides mauritanicus*, and the wasp *Nemeritis canescens*, a parasite of the mill-moth. In the room in which the " whizzer " is housed and where humidity is high, the moth *Endrosis lacteella* is often very numerous. *Ephestia kühniella* moths and adults of the parasite *Nemeritis canescens*, and of the fly *Scenopinus fenestralis*, whose larvæ feed on dust in cracks in the floor, are often found flying in the milling rooms and at rest on the windows. *Ephestia* moths are often found at rest in the machinery, especially where there is a draught of air. In dust rooms and on aspirator dust bags, mill-moths and moths and caterpillars of *Borkhausenia pseudospretella* are often seen. It appears that certain stages of all these insects can survive the cleaning and preliminary milling processes. The eggs are the stage most certain to survive them.

Since the successful operation of a mill depends on a steady flow in all parts, any blockage of chutes or machinery due to the accumulation of webbing leads to considerable interference, and where it is abundant the mill-moth, *Ephestia kühniella*, may even stop the machinery. Caterpillars of this moth and the grubs of the beetle *Tenebrioides mauritanicus* eat holes in the silks of purifiers and flour dressers, thus defeating the object of these machines. It may be noted, however, that the eggs of the mill-moth are too large to pass through the finest silks and the highest-grade flours should, therefore, be free from infestation.

In spite of all precautions taken by millers when starting up new mills the mill-moth sooner or later appears. During the survey it was frequently asked how this occurs, and the following explanation is based on the observations.

Mill-moths, although regarded as a pest of flour, can and do infest whole grain, and can readily find their way through to the mill stream. Since they occur in grain in the mill's silo, it is also possible for adult moths to fly through on to the milling floors and lay eggs in the accumulations of flour lodged in the machinery.

Cocoons and caterpillars of the moths *Ephestia kühniella* and *Endrosis lacteella*, and the beetles *Ptinus tectus* and *Tribolium castaneum*, and their grubs, have been observed on returned flour sacks undergoing cleaning, which is often carried out on one of the warehouse floors. As already mentioned, the present methods of cleaning sacks are inadequate for the complete removal of insects.

It is certain that eggs are carried from mill to mill on workmen's clothing.

Mills and warehouses are close together in the ports, and in hot weather moths will readily fly from one to another.

The interchange of goods between mills and the return of damaged flour and offals also lead to the carriage of the mill-moth and other insects from infested mills, agricultural merchants' premises, and bakeries to clean mills.

Since the caterpillars of the mill-moth produce copious webbing, the miller is forced to adopt some means of cleaning his machinery at intervals. The majority of millers adopt a regular mechanical cleaning of all parts of the machinery. This is usually carried out during the week-end when the machinery is still. In this way they manage to keep most of the machinery clear, but there are certain parts, such as flour elevators and worms, whose dismantling and cleaning take a considerable time. Moreover, during the summer, when temperatures are high, the caterpillars produce webbing at a greater speed. For these reasons most mills find it necessary to close down once a year for a thorough cleaning. Many of them are also fumigated.

Various fumigants are used and, whereas hydrogen cyanide in several forms is used in some mills with great efficacy, other mills rely solely on burning sulphur and nicotine, which may kill the adult insects but are not effective against eggs and dormant grubs and caterpillars. The penetration of these fumigants is poor, and the fumes of burning sulphur are harmful to unprotected metal surfaces.

Flour and milling offals are usually stored in the same warehouse and the flour passes through fairly quickly. Only a few kinds of insects were found on flour in the warehouses of mills—namely, the spider-beetle, *Ptinus tectus*, and the moths *Ephestia kühniella* and *Endrosis lacteella*, and then only in small numbers. On the other hand, flour stored for any length of time in outside warehouses is often infested by the beetles *Ptinus tectus* and *Tribolium castaneum*. Offals are frequently clear of insects, but bran may become heavily infested with mites during warm weather in summer when large quantities have to remain in the warehouse because of the slack demand for it then as feed for livestock.

Warehouse practice in flour mills offers an example which should be followed in all other types of warehouse. In particular, the millers carry out orderly stacking of sacks, leaving plenty of room between stacks and walls, and enforce a strict rotation of stocks and a high standard of cleanliness. The warehouse is rarely fumigated with the mill, but the hygienic precautions taken usually keep the insect population at a very low level.

Provender mills

Twenty-seven provender mills were visited, of which five were in Scotland, five in Northern England, and seventeen in Southern England.

Provender mills, which produce branded feeding-stuffs for supply to farmers, may form an integral part of a flour mill, using the offals as the basis of the feeds, or of an oil-seed crushing mill. Independent provender mills occur, however, both at the ports and inland, drawing their supplies from a number of sources.

These mills use a great variety of raw materials; one of the cattle cubes manufactured in a mill visited consisted of sixty-three different ingredients. The raw materials are stored in warehouses attached to the mills, and may remain there for considerable periods, often up to two years. Large provender mills and those attached to flour mills store their whole grain in silos. As the conditions in these warehouses and silos are similar to those in general dock warehouses, no further discussion of them is necessary, except to say that manufactured goods and raw materials are often stored together. It is interesting

to note that in one mill the raw materials are stored in large bulked piles, and are handled by a small mechanical digger. It was found that the numbers of insects in it had been considerably reduced, probably because of the absence of any sacking.

As the manufacture and sale of feeding-stuffs is a highly competitive business, millers take every opportunity of buying in the cheapest markets, and this leads to the purchase of cargoes of infested and damaged grain and other materials which are cheaper than undamaged goods. In one mill, a cargo of South African wheat had been held in store for over twelve months. When examined, this grain was very badly heated and damaged, and was "alive" with the beetles *Calandra oryzae*, *Tribolium castaneum*, *Laemophlaeus*, and *Ptinus tectus*, and the predacious bug *Lyctocoris campestris*. This grain was being ground and mixed with Plate middlings to produce a special branded middlings. The Plate middlings were infested by the moths *Plodia interpunctella*, *Ephestia kühniella*, and *Ephestia elutella*, as well as by *Calandra granaria*, and the resultant mixture was infested with all these insects together.

Another example of trade in infested raw materials was brought to notice by a railway company, following a sudden outbreak of insects in a warehouse. Investigation showed that some forty sacks of Indian wheat "sweepings" from a ship's hold had been imported from a continental port and held in the wagons pending dispatch to a number of London provender millers. The grain was found half-eaten by the following insects, which were present in large numbers: the beetles *Calandra oryzae*, *Tribolium castaneum*, *Laemophlaeus*, the parasitic insects *Lariophagus distinguendus*, *Chætosphila elegans*, *Plastanoxus westwoodi*, *Cephalonomia waterstoni*, and the predacious bug *Lyctocoris campestris*. The presence of these parasitic insects showed that the infestation was of long standing. The grain sweepings were very dusty, and contained a large admixture of stones and dirt.

One of the basic materials of feeding-stuffs is rice-bran, which is known colloquially as "lousy meal" or "buggy bran" by the dockers, since it is usually heavily infested with large numbers of the flour-beetle, *Tribolium castaneum*. In one provender mill in the west of England the walls were black with these insects above piles of rice-bran which had been in store throughout the summer, and manufactured cattle-foods stored in the same rooms were badly infested. Complaints had been received from a neighbouring flour miller whose premises had been invaded by the insects.

Other raw materials which are generally heavily infested by insects are ground-nut cake, locust-beans and meals, broken rice, foreign wheat-offals and all kinds of whole grain, especially dari and maize. A table of the extent of infestation by common insects on various raw materials is given below.

Ground-nut cake	*Common insects*
Consignments examined 64	*Tribolium castaneum*
,, infested 54 (84%)	*Ptinus tectus*
	Ephestia elutella
Rice-bran	
Consignments examined 31	*Tribolium castaneum*
,, infested 25 (81%)	*Ptinus tectus*
	Ephestia elutella
Broken rice	
Consignments examined 10	*Tribolium castaneum*
,, infested 10 (100%)	*Ephestia elutella*
	Tenebrioides mauritanicus

Locust-beans

Consignments examined 24	*Ephestia elutella*
,, infested 15 (62%)	*Ptinus tectus*

Wheat-offals

Consignments examined 263	*Tribolium castaneum*
,, infested 212 (81%)	*Tribolium confusum*
	Ptinus tectus
	Tenebrio molitor
	Tinea granella
	Ephestia clutella
	Tenebrioides mauritanicus

Dari-seed

Dari is seldom found free of insects. It is usually heavily infested and often much heated as a result of the activity of the insects.

Consignments examined 30	*Calandra oryzae*
,, infested 26 (87%)	*Calandra granaria*
	Rhizopertha dominica
	Laemophlaeus spp.
	Tribolium castancum
	Tenebrioides mauritanicus
	Ephestia elutella
	Caenocorse ratzeburgi
	Tinea granella

Trogoderma granarium (*khapra*), the serious pest of maltings, is occasionally found on these goods from India and Burma.

In the provender mill there is not the same trouble from mill-moth or other insects in the machinery as in the flour mill owing to the greater density of the materials used and to the fact that violent crushing and heat are applied in the course of manufacture. However, numbers of insects, especially the moths *Ephestia elutella*, *Ephestia kühniella*, *Endrosis lacteella*, and *Borkhausenia pseudospretella*, and the beetles *Tribolium confusum* and *Tribolium castaneum*, *Tenebrio molitor*, *Silvanus surinamensis*, and *Silvanus mercator*, may often be found in all parts of the floors carrying machinery since it is the general practice to store all raw materials, screenings, and manufactured goods near the machinery.

Large quantities of screenings and dust are often removed from the grain used in the manufacture of feeding-stuffs, especially from low-quality wheat, barley, and maize. These screenings and the dust are usually heavily infested with insects, of which *Calandra granaria*, *Calandra oryzae*, *Silvanus surinamensis*, and *Silvanus mercator*, species of *Laemophlaeus*, and *Caenocorse ratzeburgi* are the most prevalent. These infested screenings were regularly collected once a month from one mill by a farmer who used them for poultry food. Sweepings and screenings, which are sometimes bought from other mills and from warehouses, are often used in the manufacturing process. As already pointed out, these screenings and sweepings are heavily infested with insects and mites, and are thus unsuitable material for the manufacturer of balanced rations, although one manufacturer had gone to the trouble of analysing the protein content of " weevils."

In one large west-country provender mill the infestation of the premises by mites, especially the flour-mite, *Tyroglyphus farinae*, was so bad that two boys were employed full-time in sweeping. The infested dust and that extracted by the " cyclone " were fed back into the grinding machinery, thus effectively infesting all the material produced! Owing to their small size, their ability to

withstand desiccation in certain stages of their development, and their powers of rapid multiplication, mites can survive the manufacturing processes. It is said that mite-infested feeding-stuffs may lead to digestive disorders or scour in animals fed on them, but no precise information to support that has yet been obtained.

Branded feeding-stuffs which have been returned damaged to the mills are often put through part of the manufacturing process again for the purpose of " reconditioning." As this damage is often caused by insects, the return of such goods to the mill may lead to cross-infestation.

The manufactured products range from pure oilcakes to mixtures of grains, such as poultry foods. Any mixture of grains which has not undergone grinding may be infested with any or all of the insects present in the constituents before mixing. Some insects' eggs may survive grinding and so give rise to infestation of ground feeding-stuffs. Any foodstuff, however, which has been cooked, heated, or pressed, such as cooked flaked maize, nuts, cubes, and pellets or oilcake, is sure to be free from any live insects, when freshly made. Thus, in a west-country provender mill, inside a newly made dairy nut made from materials including heavily infested rice bran, all the insects (flour-beetles) found were dead. Even though goods are sterile when manufactured, the conditions of storage in most provender mills, where raw materials and manufactured goods are stored side by side, are such that they are rapidly reinfested from the resident insect population or by cross-infestation from raw materials. Thus, in one mill *Tribolium castaneum*, *Ephestia elutella*, and *Alphitobius diaperinus* were found on nuts still warm from the " cuber." The sacks of nuts were being loaded on to a lorry for delivery to farmers and agricultural merchants.

The general standard of cleanliness is low in provender mills, as contrasted with flour mills. This is true even when a provender mill forms an integral part of the flour mill.

Oat mills

One oat mill was visited, which was in Scotland.

This mill was using only Scotch oats, but a number of *Calandra granaria* were found on screenings removed from them; since there was a maize-flaking mill attached, it is possible that the *Calandra* may have come from foreign grain delivered to that mill.

Whilst oats are subjected to a dry heat of 300° to 400° F. as the first process, which is sufficient to kill all insects, the oat miller has almost as much trouble from the mill-moth, *Ephestia kühniella*, in the machinery as the flour miller. Although infestation does not appear to be so bad as to make regular fumigation necessary, *Ephestia kühniella* is probably a common pest of oatmeal because the final sieving is not sufficiently fine to hold back the eggs, but allows them to pass through with the meal.

The storage of oatmeal and various oat products is rendered difficult because they are very attractive and nutritious to many insects. Rolled oats, in particular, have been found to be one of the best foods for the rapid breeding of insects in the laboratory. The following insects have been found commonly on oatmeal: *Ptinus tectus*, *Calandra granaria*, *Endrosis lacteella*, and *Ephestia kühniella*. It is also readily attacked by mites, especially *Tyroglyphus farinae*, but one miller said that one type of oatmeal used in the preparation of " hound meal " was palatable to the hounds only when very badly mite infested!

Rice mills

One rice mill was visited, which was in northern England. A number of consignments of rice were seen in port warehouses and ships. Of these, twenty-four lots were seen in warehouses, of which only four were clear of insects.

The following insects were the most common on the imported rice: *Tribolium castaneum, Tribolium confusum, Silvanus surinamensis, Tenebrioides mauritanicus, Calandra oryzae,* and *Ephestia elutella.* The heavy infestation seen in provender mills has already been mentioned.

Most of the rice is imported as " white rice," but small quantities of " paddy " and " brown rice " are brought in. At one west-country port a special rice-cleaning machine has had to be installed in the warehouse for the removal of insects as a result of the large number of complaints from purchasers of rice delivered from the docks. All the rice, both screened and unscreened, in this warehouse was found to be infested with the beetles *Calandra granaria, Calandra oryzae, Tribolium castaneum, Tribolium confusum, Tenebrioides mauritanicus, Silvanus surinamensis, Necrobia rufipes,* and *Lasioderma serricorne.* When the screening machine was started up, a stream of rice and insects poured out, not only from the " screenings " spout but also from the " clean " spout. In addition to the insects listed above, the moth *Sitotroga cerealella* and the beetle *Alphitobius diaperinus* also came out of the spouts.

The principal processes in the rice mill consist of the polishing and grading of whole rice and the grinding of rice flour and broken rice. *Ephestia kühniella* causes considerable interference with the machinery in the same way as in flour mills. Rice flour is sufficiently coarse to permit eggs of this moth to pass through the final silks. It was stated that a fair proportion of the polished rice and rice flour has to be returned to the mill for reconditioning, owing to webbing and damage by the larvæ of this moth. In addition to *Ephestia kühniella,* other insects present in the machinery and premises were *Ephestia elutella, Calandra granaria, Calandra oryzae, Silvanus surinamensis, Silvanus mercator,* and *Tribolium castaneum.*

The process of polishing whole rice removes only adults and free-living larvæ (caterpillars and grubs), and does not affect larvæ living within the grains, such as those of the *Calandra* beetles. The infestation of whole rice, even after careful cleaning, is due to the development of these larvæ.

Agricultural Merchants' Premises

Under this term are included all merchants dealing in grain, cereal products and branded feeding-stuffs. They usually have equipment for grinding grain and cleaning seed, and their premises are mostly situated in market towns. Their main business is with farmers in the neighbourhood.

The agricultural merchant acts as the last link in the supply of feeding-stuffs to the farmer. He usually keeps a very varied stock in his warehouse, which is often a rural mill. The premises are usually old buildings, quite unsuited to the storage of grain and cereal products under clean conditions. Even where specialized modern buildings are used, the standard of general hygiene is low. The goods are too often stored under conditions of great congestion, raw materials, machinery, manufactured feeding-stuffs and seed grain being all crowded together. Under these conditions regular cleaning and rotation of stocks cannot be carried out. The premises are usually overrun with rats and mice, and this results in the spilling of the contents of sacks.

Since the agricultural merchant draws his supplies from port warehouses and provender mills, he often receives infested materials, and the congested storage in his premises leads to the rapid infestation of all his stock, even those parts of it which arrive clear of insects. Some manufacturers of feeding-stuffs have established their own private distributing centres, instead of following the more common practice of appointing agricultural merchants as their agents. These private stores are usually clear of insects, or are only lightly infested. The general condition of the fabric of the agricultural merchants' warehouses

and the resident insect populations they harbour are similar to those of the old warehouses.

Owing to the congested storage, it is not always possible to assign the sources of infestation to particular goods, although the nature of the infestation is generally similar to, but often much heavier than, that on the imported raw materials and manufactured goods in port warehouses and provender mills. The following insects are the most common in the agricultural merchants' warehouses in all parts of the country: *Calandra granaria, Calandra oryzae, Tribolium castaneum, Tribolium confusum, Silvanus surinamensis, Silvanus mercator,* species of *Laemophlaeus, Ptinus tectus, Tenebrio molitor, Borkhausenia pseudospretella, Endrosis lacteella,* and *Ephestia elutella.* All the kinds of grain pests in the Royal Society Grain Pests (War) Committee's list have been found in these premises at one time or another. *Tenebrio molitor* and *Borkhausenia pseudospretella,* in particular, are insects which thrive under dusty and dirty conditions, and form a sure indication of chronic lack of cleanliness in the warehouses where they abound.

All agricultural merchants hold great varieties of stocks, and those who are agents for branded feeding-stuffs are obliged to store many lines, for some of which there may be only a limited demand. On these goods held in store for a long time the attacks of insects and mites lead to such damage that they may become unsaleable and have to be returned to the makers, carrying with them a large or small number of insects, according to the degree of infestation in the warehouses.

The operations which the agricultural merchant carries out are grinding, clipping, kibbling, seed cleaning, and the preparation of special meals to order, either from stock or from grain delivered to the agricultural merchant by the farmer himself. Many farmers are dependent on the services of the agricultural merchant for the grinding of grain and the breaking and kibbling of cake. For this purpose they often send their grain to the agricultural merchant, who returns it to them after processing. It has already been shown that any goods entering the warehouse rapidly become infested with a variety of insects, and the infestation of the farmers' own grain which takes place in these premises is one of the main reasons why insects reach the farms. Insects do not interfere with the operation of the machinery in these merchants' mills, but the great range of materials processed in a single machine leads to considerable cross-infestation.

Agricultural merchants act as corn merchants, buying grain from farmers and selling it to other farmers and to millers and brewers. In the course of these operations the grain is often stored in the warehouse, where it may rapidly become infested. The depots of sack-hiring companies are also often situated in the agricultural merchants' warehouses, and these merchants often deal in second-hand sacks and offal bags. The part played by sacks in the spread of insect pests has already been considered.

Some agricultural merchants also act as agents for seedsmen and clean and dress farmers' own seed grain. It has frequently been observed that seed grain, after being cleaned, has been stored in the warehouses in close proximity to badly infested goods. In one warehouse in the south of England several sacks of sweepings and screenings (heavily infested with weevils, the bug *Lyctocoris campestris,* and booklice) were stacked with the seed-wheat and piled against the seed-cleaning machine. All the seed-wheat in this warehouse was infested with *Calandra granaria* and other insects. Each grain attacked by this insect represents a direct loss, since it will not germinate successfully. These observations do not apply to separate seed stores and to the premises of seed merchants proper, which have been found to be remarkably free from pests.

As the agricultural merchant receives not only infested raw materials direct

from the ports and manufactured goods from provender and flour mills, but also home-grown grain from farmers in his district, it is often in his premises that the home-grown grain first becomes infested. One agricultural merchant with a considerable trade in home-grown malting barley was found to be blending and mixing the grain in a warehouse which was badly infested with *Calandra granaria*, derived from imported infested goods in another part of the building. It is not surprising that some of the barley was returned by a well-known firm of brewers because they found it infested with " weevil."

Insect infestation represents a serious problem to millers and agricultural merchants, and it has been shown that much of the trouble arises from the use of imported materials which are badly infested. While flour millers show an appreciation of the problem of infestation, and take chemical and mechanical measures to deal with it, provender millers and agricultural merchants, with rare exceptions, neglect it entirely. As a result, the premises of the latter now harbour a large resident population of pests, which are capable of maintaining themselves for an indefinite time, even when their numbers are not augmented from imported goods. This resident population is of especial importance in the agricultural merchants' warehouses, since these store not only imported goods but also home-grown grain and seed, which become infested in their turn. As so many of these feeding-stuffs are infested, there is a constant interchange in insects from place to place, so that any newly introduced pest is rapidly spread over the country. (See Fig. 12, p. 10.)

SEED MERCHANTS

Seed-grain is generally handled in small warehouses equipped with cleaning machines and dressers. The dresser is used to treat the seed with various fungicides before delivery to the farmer. All types of seed are warehoused, but the main bulk consists of cereal seeds. Much of this grain is stored and treated in the warehouses of agricultural merchants, and is rapidly infested there by many insects, especially *Calandra granaria* and *Calandra oryzae*. The attack of any insect or mite which eats the embryo or reduces considerably the amount of reserve food material in the endosperm represents a direct loss to the purchaser, since each damaged berry may fail to germinate.

For this reason, among others, some agricultural merchants keep their seed in separate warehouses or in those of merchants who deal only in seeds. None of the serious pests, such as *Calandra* or *Silvanus*, have been found in these separate warehouses, and one warehouse visited in the north of England was an old tithe barn that had been in continuous use for the storage of seed for many years. The only insects found in these stores are those which are seldom absent from any warehouse, such as the beetles *Ptinus tectus*, species of *Cryptophagus*, and the bug *Lyctocoris campestris*.

The relative paucity, or the absence, of insects is due to a number of causes. Most of the seed-grain passing through these warehouses is home-grown grain, delivered direct from the threshing machine on the farm, and is not allowed to be stored in the farm buildings. All seed-grain is carefully cleaned of any weed seeds, dirt and light grain, and this process removes any free-living insects which might have found their way on to the grain. The building, too, is generally kept clean. It should be mentioned that the treatment of seed with organic mercurial dressings does not appear to prevent attack by insects. Most seed merchants store cleaned seed in new sacks, which are delivered direct from the sack companies. These new sacks are usually free from insects, in contrast to those sacks which have been used previously for the carriage of infested goods or have been stored in infested premises. Seed-grain stored in special

warehouses does not come into contact with imported or home-produced goods which are infested, and cross-infestation cannot occur, provided the warehouse is sufficiently far from any infested premises and the men handling seed have not recently been handling infested goods elsewhere. No insects have been found on imported seeds, which come mainly from Denmark and New Zealand.

FARMS

One hundred and eighty-seven farms were visited, of which 15 were in Scotland, 37 in northern England, and 135 in southern England. They were chosen from many types—namely, mixed farms, farms growing grain as the principal crop and harvesting it either by reaper and binder or by combine harvester, and specialized farms such as agricultural institutes, poultry farms, pig farms, and market gardens.

Farm buildings vary considerably in their construction and maintenance. Large farms operated on a commercial basis, such as large pig-breeding and grain-producing farms, have modern buildings which are kept in a good state of repair and cleanliness. The condition and cleanliness of buildings on other farms was found to vary considerably in different parts of the country. In England they are generally in poor repair, especially on the small farms. On the farms in the north, however, and particularly those in Scotland, the buildings are much better. As the majority of farm buildings in England are at least a hundred years old, the materials used in their construction are very varied and are usually of local origin. The barn of one farm visited originally formed part of a monastery dissolved at the Reformation. The building showed many cracks and crevices, which form ideal breeding-places for the resident insect population. Attempts have been made to render these old buildings more suitable for the storage of grain and feeding-stuffs by matchboarding and by cementing the walls and replacing flooring, concrete being used for the ground floors. The buildings of the more modern farms have been constructed in the light of past experience for specific purposes, and in these the storage places usually have fairly smooth surfaces. The problem of storage on the farm is complicated by the fact that the farmer not only receives grain and feeding-stuffs from outside sources, but also grows them himself.

The method of storing grain grown on the farm depends on whether it is unthreshed or threshed. Unthreshed grain is mainly stored in ricks or Dutch barns, but may be stored in the barn. None of the pests of stored grain have been found in unthreshed grain out of doors, nor have they been recorded from standing crops, although the *Calandra* weevil has been seen occasionally crawling about out of doors during the summer.

Threshing is generally carried out during autumn, winter and spring according to the need for straw. Shortly before threshing the farmer arranges with a sack depot or the purchaser of the grain for a supply of grain sacks. These are stored in the farm buildings until required. The threshed grain is stored in these sacks in the granary or barn until collected by the purchaser. The period of storage rarely exceeds two weeks. Tailings are retained by the farmer, and may be kept in the granary for considerable periods. Some of the worst infestations on farms have been seen in tailings.

Very damp grain cannot be left in sacks and may have to be spread on the floor of the granary for some time to dry. Malting barley is spread and mixed on the barn floor in order to obtain an even sample, and is then stored in hired sacks. In Scotland the threshing machine is generally an integral part of the farm buildings, and the grain is conveyed in bulk direct to the granary floor. It is sacked only when ready for delivery to the purchaser. On farms using the

combine harvester the grain is taken from the field, either in bulk lorries or in bushel sacks, usually old fertilizer bags kept for this purpose. In the farm buildings the grain is dried and generally stored and handled by methods similar to those used in silos.

Farmers' own grain becomes infested only when it is placed in infested sacks or in buildings where there is a resident population of insects or comes into contact with infested grain or feeding-stuffs.

The farmer derives the main bulk of his feeding-stuffs from the agricultural merchants' warehouses, although supplies are also received direct from mills, warehouses at ports, breweries, maltings and distilleries and from other farms. (See Fig. 12, p. 10.) The nature of the infestation of the products of these places has already been described, and it has been shown that all these feeding-stuffs are usually heavily infested with insects. The insects brought into the farms on any of these goods establish themselves in the buildings in which, owing to the low standard of cleanliness and the activity of rats and mice, there is always plenty of loose meal and grain. As the farmer usually receives supplies of feeding-stuffs at frequent intervals, this resident population is periodically augmented. Feeding-stuffs are stored in the granary, the barn, and sometimes in completely separate feed stores. They are almost always left in the original bags, although the contents are sometimes stored in open or closed wooden or cement bins or shot in loose piles on the floor of the granary or barn.

The following examples show how infestation in the farms has been caused by insects carried from agricultural merchants' warehouses. Several farms in the South were examined in which sacks of wheat from a warehouse were seen three days after delivery. At each farm the sacks were covered with large numbers of *Calandra granaria*, *Silvanus surinamensis*, *Tribolium confusum*, *Caenocorse ratzeburgi*, and *Ephestia elutella*. Few insects were found on other grain and feeding-stuffs at these farms, but the warehouses from which this grain had come was very dirty and overrun with large numbers of insects of many kinds. As already mentioned, many farmers send grain to the agricultural merchant for grinding. This grain, ground and mixed with other meals, is often sold back to the farmer, together with any insects which may have got on to it in the warehouse. Other grains are ground to order. One agricultural merchant in Buckinghamshire refused to grind oats for a farmer, owing to the presence of large numbers of insects in it (*Silvanus surinamensis*, *Calandra granaria*, and others). Investigation showed that these insects must have been introduced to the farm on oats ground for the farmer on a previous occasion by the agricultural merchant himself, since the farmer dealt solely with this merchant and bought no feeding-stuffs or grain.

The most common insects which may be regarded as permanent residents in farm buildings are the beetles *Ptinus tectus*, *Tenebrio molitor*, and species of *Cryptophagus*, the moths *Endrosis lacteella* and *Borkhausenia pseudospretella*, the bug *Lyctocoris campestris*, and mites. In Scotland the beetle *Eurostus hilleri* was found to be widespread; in the south of England *Calandra granaria* may possibly be regarded as a permanent resident in those farm buildings to which it has been carried. Moths and beetles[1] fly from farm to farm in the adult stage, and are often attracted to lights in farm buildings. In Yorkshire the moth *Tinea ditella* was commonly found on farms.

Other insects introduced on feeding-stuffs are *Calandra oryzae*, *Tribolium castaneum*, *Tribolium confusum*, *Silvanus surinamensis*, *Caenocorse ratzeburgi*, *Ephestia elutella*, and *Tenebrioides mauritanicus*. All of the pests found in other sections of the trade have been found at times on farms, but it appears that the conditions of storage on farms are such that the insects just cited have not established themselves to any extent. *Calandra* was present on 70 farms

[1] *Calandra granaria* cannot fly, although *Calandra oryzae* can.

(37 per cent.) and, whereas half the farms in southern England have *Calandra* present, the proportion is considerably less in the North and in Scotland. Even though this proportion is low in the North, one farm which was visited in Yorkshire had a badly infested granary. A consignment of infested maize had been stored there some two years previously, but had been cleared out as soon as the farmer observed weevils. The granary had then been left empty throughout two seasons and measures of control had been attempted. During the second summer, when it was visited, large numbers of beetles (*Calandra granaria*, *Silvanus* species, *Cryptophagus* species, and *Tenebrio molitor*) and moths (*Endrosis lacteella*, *Borkhausenia pseudospretella*, and *Tinea metonella*) as well as a parasite of *Calandra* (*Lariophagus distinguendus*) were found. All these insects had maintained themselves for this time on grain in the fabric of the building. On a farm in Hampshire a large quantity of the farmer's own wheat of the previous harvest, stored in a bin in the granary, had been completely destroyed by *Calandra granaria*. The grain was very hot, and when disturbed thousands of grain weevils appeared on the surface of the grain. Further examination of the farm buildings, which were in excellent repair and in which the walls were lined with matchboarding, revealed the presence of large numbers of *Calandra* in addition to other insects in all parts, especially behind the matchboarding. They were so numerous that new-crop rye and oats, which had been in the buildings only about a week, was heavily infested.

The occurrence of insects on feeding-stuffs and grain does not appear to cause the farmer serious concern, but should weevils be found on his malting barley by the maltster the value of the crop may fall at least 50 per cent. It has been shown that farm buildings are infested with all kinds of pests, and that infestation arises from infested sacks or from insects invading this grain during storage in the farm buildings.

Feeding-stuffs are generally infested. If these are stored for any length of time on the farm the insects multiply rapidly and may cause direct loss of material. For example, on another Hampshire farm the whole surface of sacks of dairy and other nuts was covered with a sheet of webbing produced by the caterpillars of *Ephestia elutella*, and the room was thick with moths. On a farm in Yorkshire sacks of tares were rendered useless as the result of attack by the caterpillars of the moth *Endrosis lacteella*. As stores on the farm are generally damp, conditions for the rapid development of mites are ideal, and they are often found in damp grains and feeding-stuffs, especially chaff, pig meals, wheat bran, and maize meal.

A frequent condition in farm granaries and barns is a jumble of half-used sacks of feeding-stuffs, discarded bags and old sacks, all mixed up together. Only rarely is regular cleaning carried out, and the state of the buildings makes fumigation impracticable.

Grain and feeding-stuffs rarely remain in store long enough for serious destruction to result from attack by insects. Instances have been given where damage has occurred when grain or feeding-stuffs have been stored too long, but the most serious problem is the infestation of the farmer's own grain before it leaves the farm. Examples of loss from this cause have been given. This is probably one of the reasons why a few farmers stated that they refuse to accept feeding-stuffs on which they find insects. If all farmers would insist on clean feeding-stuffs the infestation of home-grown grain lying on the farm premises would be considerably reduced. So, too, if the practice of retaining a special building or part of a building for home-grown grain were universally adopted, infestation of it might gradually cease. Out of 190 farms visited 68 followed this practice. Out of 75 barns or granaries which had been set apart in this way and used only for home-grown grain, 72 were free from grain-weevils and 24 contained no insects at all.

BREWERIES, MALTINGS, AND DISTILLERIES

Breweries and Maltings

The premises of 38 firms were visited, and answers to questionnaires were received from 27 other firms.

The buildings of maltings are usually well constructed and maintained in good repair. Most of them are situated in or near towns with ready access to imported barley, which is often carried to them by canal or river. There is a large number of country maltings in the Eastern Counties, where there are ample supplies of home-grown barley. (See Fig. 12, p. 10.)

The principal grain malted is barley, although small quantities of wheat and rye are used as well. In addition to English, much imported barley from California, Poland, Australia, India and Chile is used. The proportion of English barley used is increasing as a result of an agreement between the farmers and the brewers. The grain is carried mainly in sacks and subjected to as little rough handling as possible in order to avoid damage to the "beard." On arrival at the malting, the grain is examined for signs of weevils and khapra-beetles, since some firms make the presence of these insects grounds for refusal to accept delivery. Thirteen out of 27 maltsters consulted on this point replied that they refuse infested grain. One maltster and grain merchant even refused to deliver Indian barley to his customers when he found it infested with *Trogoderma granarium* in the ship. After examination the grain is screened to remove weed seeds and dust, and is stored in lofts in bulk or in sacks. The floors of these lofts are constructed of close-fitting boards, and there is little room between them for grain to collect. The walls, however, are often lined with matchboarding behind which grain collects and provides a secure breeding-ground for insects. The lofts are usually swept regularly and are frequently sprayed with insecticide. During the summer, when insects are most active, little or no grain is stored, since malting is not carried on during hot weather. Last season (1938) was exceptional, and some maltsters did store large stocks of grain, which soon showed infestation. On the other hand, it is during this time that large supplies of malt are usually stored.

Before malting begins the barley is steeped in water for about 48 to 72 hours. In this process any adult beetles generally float to the top of the steep, and may walk up the sides and on to the malting floor. There is evidence to show that grubs within the grain can survive this period of immersion. The grain is then spread on the floor to germinate, and remains until a malt of the required quality is produced. Pneumatic maltings are occasionally used, and they have the advantage of much closer control of temperature. The constant disturbance of the barley in the drums and the general conditions do not appear to be favourable for insects. The germinated barley is then taken to the kiln, where it is dried at a temperature which may reach 240° F. After removal of the culmings, the malt is stored either in sacks or in bulk in bins until required. These bins are often constructed near the kiln so that the malt will remain dry, and since the bins are made of wood there are usually accumulations of dust and grain in cracks and crevices between the boards. To prevent this, bins have been lined with metal, but grain nevertheless finds its way between the metal and the wood. The most efficient bins of this type were seen in a Scottish brewery, where the floors had been covered with Trinidad pitch and the walls and ceiling with close-fitting American cloth, painted with a glossy finish. Some maltsters have now fitted self-cleaning metal bins for the storage of malt. It has been shown above that much of the imported barley is infested. Out of 33 maltings inspected, 31 were found to have *Calandra granaria* present. Of 14 maltings which use no imported barley, 13 were infested with *Calandra granaria*.

This indicates that much of the English barley must become infested before it reaches the maltster. The presence of *Calandra* in a malting represents a direct loss, since no extract can be obtained from grains which are so damaged that they will not germinate. Moreover, those which do germinate may have the endosperm completely eaten. The insects common in stored barley are *Calandra granaria, Ptinus tectus, Niptus hololeucus,* and *Silvanus surinamensis.* The only insect found in any large numbers is *Calandra,* and this has been found both on foreign barleys and on English and Scottish. Norfolk barley was seen in a Scottish malting only a few days after delivery, and numbers of *Calandra granaria* were found on it. In the course of malting many of the weevil grubs within the grains complete their development and emerge. They are found commonly on the walls and in the germinating grain of greater age, which is usually somewhat warmer than the grain which has not yet sprouted. Weevils are also much more numerous at the kiln end of the floor, since this wall is very warm. It is here that khapra-beetles are usually first to be found in any numbers in an infested malting, although they sometimes occur in small numbers in the barley lofts. The number of maltings in which khapra-beetles were found was 10 out of 38. These insects are the major pest in the malt stores, where they are found sometimes in colossal numbers. The most common species is *Trogoderma granarium* (khapra); *Trogoderma versicolor* also occurs and may be found with it. The larvæ or grubs of these beetles are far more evident than the adults, which have only a short existence. They are usually seen in large numbers in the cracks between the boards of malt bins and on the ground below them. It is their habit to remain crowded in ranks in large numbers in very confined places, and they are able to penetrate into exceedingly narrow cracks. For this reason, in infested maltings the whole fabric of the building, especially the warmer parts, such as the kiln and malt stores, are permeated by these insects. For example, in a malting where a closely fitting steel girder had to be removed from a wall, the whole of the inner surface was found to be packed with *Trogoderma* larvæ. Before the girder was removed it was impossible to insert a knife blade anywhere between the girder and the wall. *Trogoderma* is usually introduced into maltings on Indian barley, but it has also been carried in on returned malt sacks, on malt from other maltings and in whole grain sent from one malting to another. It may also be introduced on imported grain from other countries which has become infested in the ship or during storage at the port. For example, it has been found in large numbers in ships on ground-nut cake and Indian wheat, and in spite of its known preference for warm conditions it was found in the fabric of a warehouse in the port of Aberdeen during March.

This insect not only causes considerable annoyance by its mere presence in large numbers, but directly damages the malt. It eats the grain, while the dead bodies of the larvæ render the grain sour and raise the water-content of the malt, making it unfit for use by the brewer.

The principal product of breweries, beer, is not infested by grain insects. A number of by-products which are used as feeding-stuffs, and which are often sent direct from maltings to agricultural merchants and farms, have frequently been found to be infested in maltings and elsewhere. These by-products are wet and dried grains, malt-culmings and spent hops. It is generally only on dried grains and malt-culmings, which are packed in sacks, that insects are found, and of these the most common are *Calandra granaria, Ptinus tectus,* and *Borkhausenia pseudospretella.* Dust and screenings from the barley are sold and are generally infested by *Calandra granaria, Ptinus tectus, Borkhausenia pseudospretella, Tenebrio molitor, Endrosis lacteella,* and occasionally by *Trogoderma.* Many maltsters and brewers supply these by-products to farms from which they obtain supplies of barley. (See Fig. 12.)

Some maltings are equipped for the production of malt flour, and then *Ephestia kühniella* and *Tenebrioides mauritanicus* may cause the same kind of trouble as in wheat-milling machinery.

Distilleries

All the distilleries and yeast factories examined were in Scotland, and of the total of nine visited six were Highland pot-stills using only barley.

The handling, storage, and processing of the barley is similar to that in brewers' maltings, with the exception of the longer time it is left on the malt floor or in the pneumatic drums, the lower temperature of the kiln and, in the Highlands, the use of peat instead of coal for firing the kiln. The temperatures in the malt on the floor of the kiln rarely rise above 160° F., but those on the walls are considerably lower, often not exceeding 75° F. Preliminary experiments at a Highland distillery showed that, whereas all the weevils (*Calandra granaria*) enclosed in 3″ × 1″ glass tubes containing damp malt and placed either in or on the surface of the malt were killed, those hung on the walls at about three to four feet above the malt survived, especially those above the shutter leading to the malt deposit, where a cool draught (60° F.) entered. The higher temperatures of brewers' malt kilns are generally fatal to insects, but many maltsters believe that this is not so.

In addition to the types of malting barley already described others are also suitable for the distiller. Danish Island barley is used extensively, and large quantities of Canadian Western feeding barley are also purchased. Only one of the 53 consignments of Canadian barley examined was found to be infested by *Calandra granaria*, and the majority were free from any insects whatever. Danish Island barley has been found to be infested by weevils, and saw-toothed beetles (*Silvanus surinamensis*) shortly after discharge from the ship.

Large quantities of maize are also used by distillers for digestion with the barley malt. The large distilleries, which do not usually malt on their own premises but rely on supplies from Highland and other maltings, store both malt and maize in silos, the grain being delivered from storage at the port in railway vans in bulk. The problems of infestation in silos have already been discussed. White Hickory King (South African) maize is the most used, and this has been generally found to be heavily infested with the following insects: *Calandra oryzae*, *Calandra granaria*, *Silvanus surinamensis*, *Tribolium castaneum*, *Tribolium confusum*, and species of *Laemophlaeus*. The numbers of insects on this maize are often very large. For example, a pile of such maize, examined in a transit shed in a Scottish port, was black with these insects, which had done considerable damage to the grain and also raised its temperature from 44° F. (the temperature of the air) to 103° F., measured at a depth of one foot from the top of the pile. One of the objections of both brewers and distillers to the presence of insects in large numbers in their grain is this heating, which may destroy the germinating power of barley and alter the constitution of the maize.

Before mashing, the malt and maize are ground and stored in bins. The moth *Endrosis lacteella* is often found in these bins.

The use of imported barleys by the Highland distilleries producing peat-cured malts has led to the introduction and establishment of the common pests of grain. None of these distilleries visited was free from *Calandra granaria*, and one, north of latitude 57 degrees on the west coast, had one of the worst infestations of *Calandra granaria*, *Silvanus surinamensis*, and *Silvanus mercator* that had ever been seen. Much of the malt, stored in wooden bins against two walls of the kiln, had been completely eaten out, and in addition large numbers of *Calandra granaria* were found in the barley lofts and massed together in crevices in the walls of the malting floors. This malt was examined in March, and it was the intention of the distiller to hold it in store over the summer to enable

him to begin distilling again in September without having to be delayed by malting new barley. Two distilleries in the Highlands have experienced infestation by khapra-beetle, and in one, over 600 feet above sea-level, the beetle is well established in the malt stores. Drastic measures in the other, taken some two years ago and including the complete demolition of two malt bins and the treatment of the walls with a blowlamp, had been successful in its eradication.

Similar by-products to those of brewers' maltings are produced and sold to farmers by the distilleries, and there is little difference in the infestation.

By the attacks of insects, particularly weevils and khapra-beetles, the brewers, maltsters, and distillers have been put to considerable inconvenience, financial loss, loss of goodwill and prestige. For these reasons brewers have spent large sums in equipping their plants with steel bins for the storage of malt, in making other structural alterations and in fumigating their premises.

SUMMARY AND CONCLUSIONS

The most important result of the survey is that it demonstrates the occurrence of infestation throughout all the industries producing, housing, transporting, trading in, manufacturing, or using cereals and cereal products. None of the industries, nor any section of them, can point an accusing finger at another and hold it responsible for the general evil.

To those who have had experience of infestation in other industries, who have endeavoured to assess the extent of infestation in them, and have now been privileged to carry out this survey with the co-operation of the grain industry, the outstanding feature of the survey is the fact that infestation is no longer concealed. When the informal committee of the various parties interested in the problem decided to recognize it publicly, it took the most far-reaching—as it was also the most daring—step in combating the evil. This report makes the facts known to all the members of the Standing Conference, and naturally the question now is what is to be done to reduce infestation and ultimately to eliminate it. There is no single remedy, and there will be no startling or easy remedies.

The survey shows clearly that the intensity and kind of infestation varies with the conditions of trading and with the conditions prevailing in the grain stores, be they warehouses, mills, merchants' stores, or farms, and that the first remedy is already at hand in the rather prosaic form of improved hygiene or cleanliness. That improved cleanliness should include agreement among all sections of the industry concerned to regard the deliberate concealment of knowledge that a parcel or a warehouse is infested as a breach of fair dealing. The most effective step that industry could take now is, of itself, to declare infestation "a notifiable disease."

In this report, evidence is furnished of the value of the relatively simple methods of control.[1] Good ventilation, assisted by reasonable spacing of parcels, general cleanliness, segregation (or, where need is, destruction) of infested parcels, of sweepings, grain, or offals of little value, and regular rotation in the handling of parcels and empty sacks, all have a marked effect in reducing infestation. These are measures within the capacity of all sections of the grain industry. It may be helpful to express the opinion formed in the course of the survey about cleanliness in premises. It appeared that while, in general, the executives in the industry fully appreciate the need for hygienic measures, some of the operatives fail to understand them and regard them as trivial and

[1] These have been outlined in the leaflet "Common Pests of Grain," prepared at the request of the Conference by the Department of Scientific and Industrial Research; see note on page 5.

tedious. Not infrequently operatives were seen brushing or shovelling infested sweepings into bins when they thought they were not observed. Slackness like that can, however, easily be remedied.

A second point of importance emphasized by the survey is that while the grain industry is fully aware of the paramount importance of cool and dry conditions of storage, it has not felt it necessary to develop more scientific methods of securing them. Compared with the elaborate processes devised by the milling engineers for the cleaning, conditioning and refining of flour, the processes of storage as generally practised are almost crude.

The major problem in storage is the regulation of humidity and temperature, and in modern silos it is, of course, attempted; but it seems that until the causes of rise of temperature and humidity in stored grain, with its consequences of "sweating" and "mintiness," are better understood, effective regulation will not be attained. The problem of "heating" is basically a biological one, but it is surprising to find that, although in recent years various investigators have nibbled at it, no serious organized study of the changes, physical and biological, which take place in grain during storage has been urged by the industry itself. The Pest Infestation Research Committee of the Department of Scientific and Industrial Research, however, anticipating this report, has included such an investigation in its programme. The investigation is a complex one; rapid results cannot be expected from it, and meanwhile palliative measures for reducing and controlling infestation will have to be considered.

In dealing with any problem, scientific or industrial, the first essential is to define it. The survey has been of the greatest value to the scientists in defining the basic problems of infestation. In the first place, it has emphasized the dual nature of the problem. As it is unreasonable to expect the dock or the transport authorities to provide clean warehouses and vehicles only to receive parcels of imported commodities that are infested by insects, so too it is unreasonable to ask those overseas to ensure freedom from infestation in their goods if they are to be housed in infested premises or transported in infested vehicles. In other industries this question—which parties, the importing or the exporting, shall first take action—has resulted in stalemate except in one section of the dried-fruits industry. The Australian Dried Fruits Board, which manages that industry in Australia and through its London agency handles and markets its produce in this country, cut short the discussion of responsibility for infestation between the Australian producers and its agency in London by firmly tackling the problem in this country. The result is that in the last five years the infestation of Australian dried fruits on the home market has become negligible. It may be admitted that the position of the Australian Dried Fruits Board is a special one, but that does not dispose of the fact that, by making a beginning in this country, the Board is now, and has been for at least three years, "on top" of its problem.

There are good reasons why the grain industry might adopt the same line of action. The first is that by financing the survey it has defined the character and extent of its problems. There is no evidence that the grain-exporting countries have done that. Again, by publicly recognizing infestation and inviting the help of the Department of Scientific and Industrial Research, the grain industry (in common with the other industries which have joined the Standing Conference since its establishment by the Department) has acquired the machinery through which investigations can be conducted, first to provide effective palliative measures for use in this country and then to promote the application of these methods by the exporters with whom the industry trades. Already, as a result of the survey, the Department is in contact with the Commonwealth Council for Scientific and Industrial Research of Australia about the infestation of Australian grain arriving in this country.

Admittedly, while a high degree of infestation continues to occur in imported cereals and cereal products, hygienic methods alone will not control infestation in this country and further remedial measures must be considered. Of these measures, the most likely to give immediate results is the use of insecticides. Three considerations govern and restrict the choice and use of insecticides: that they should not taint the grain or any products made from it; that they should not increase the risk of fire; and that they should be effective in destroying the insects.

These considerations impose severe restrictions on those devising or providing the insecticides and, as has been indicated earlier in this report, it is doubtful whether a really effective insecticide suitable for general use in warehouses and stores and for the disinfestation of vehicles is yet available. Meanwhile the question of risk of taint by insecticides is already being considered by the Department of Scientific and Industrial Research, and through the co-operation of the Research Association of British Flour Millers and the Brewers' Institute experimental work on the more likely insecticides is in progress. Three kinds of insecticides are being investigated—dusts, sprays, and fumigants.

The Department of Scientific and Industrial Research has also drawn up regulations for the testing of insecticides generally, and provision is being made for the conduct of the tests.

One further matter arising from the survey deserves mention. While the grain-weevils, the flour-beetles and the mill-moth are essentially pests of cereal and cereal products, nearly all the other insects whose names appear so frequently in this report are pests of stored products generally. Obviously the grain industry is justified in looking to other industries whose raw materials and products are subject to infestation for co-operation in dealing with this wide and important problem.

In conclusion I wish especially to express thanks to Sir Edwin Butler, Chairman of the Grain Infestation Survey Committee, and Mr. McAuley Gracie, Chairman of the Standing Conference, for their unfailing encouragement and advice throughout the survey.

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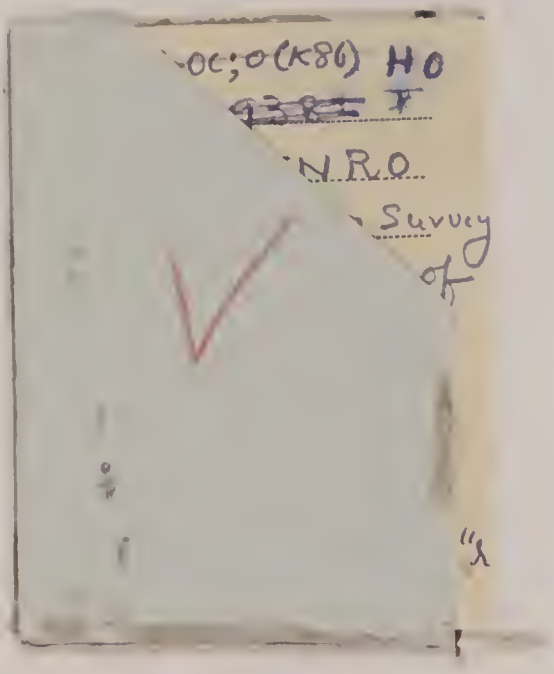
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